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ABSTRACT

This report analyzes what the Office of Technology Assessment (OTA) identifies as four pressing challenges for the Federal Research System in resource allocation and funding for research in the 1990s: (1) setting priorities in funding; (2) understanding trends in research expenditures; (3) preparing human resources for the future research work force; and (4) supplying appropriate data for ongoing research decisionmaking. Additionally, the report examines the Federal Research System: the executive and legislative branches and the research agencies. Also discussed are the value of science and the changing research economy. The report contains several appendices which include the following: major legislation enacted since 1975 affecting U.S. research and development; the top 100 institutions ranked by amount of Federal research and development funding received for fiscal year 1989; the top 100 U.S. academic institutions ranked by Citation Impact, 1981-88; and academic and basic research decisionmaking in other countries. A list of OTA workshop participants, reviewers, and contributors is provided. Contains an index and 604 references. (GLR)

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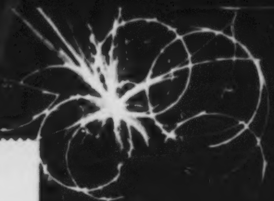

FEDERALLY FUNDED RESEARCH: Decisions for a Decade

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CONGRESS OF THE UNITED STATES
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Foreword

The Nation relies on federally funded research to address many national objectives. With global competition, changing student demographics, rising demands for research funds, and the prospect of constricted budgets, Congress and the executive branch must make difficult choices in supporting U.S. science and engineering. The House Committee on Science, Space, and Technology asked OTA to examine the Federal research system—a conglomeration of many separate systems that sponsor, oversee, and perform research—and the challenges that it will face in the 1990s.

Given the exceptional history, strength, and character of U.S. research, there will always be more opportunities than can be funded, more deserving researchers competing than can be sustained, and more institutions seeking to expand than the prime sponsor—the Federal Government—can fund. The objective for government, then, is to ensure continued funding for a full portfolio of first-rate research and a high-caliber research work force to assure long-term scientific progress. This report analyzes what OTA identifies as four pressing challenges for the research system in the 1990s: setting priorities in funding, understanding trends in research expenditures, preparing human resources for the future research work force, and supplying appropriate data for ongoing research decisionmaking. Managing the Federal research system requires more than funding; it means devising ways to retain the diversity and creativity that have distinguished U.S. contributions to scientific knowledge.

The advisory panel, workshop participants, reviewers, and other contributors to this study were instrumental in defining the key issues and providing a range of perspectives on them. OTA thanks them for their commitment of energy and sense of purpose. Their participation does not necessarily represent endorsement of the contents of this report, for which OTA bears sole responsibility.

John H. Gibbons

JOHN H. GIBBONS
Director

Federally Funded Research: Decisions for a Decade
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Chairman, Research Institute, Cleveland Clinic Foundation

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Carnegie Corp.

Purnell Choppin
President
Howard Hughes Medical Institute

Herbert Doan
Consultant
Midland, MI

Gertrude Elion
Scientist Emeritus
Burroughs Wellcome

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

Federally Funded Research: Decisions for a Decade
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John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

Nancy Carson, *Program Manager*
Science, Education, and Transportation

Daryl E. Chubin, *Project Director*

Elizabeth Robinson, *Principal Analyst*

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Political Economy Research Institute, Inc.
John W. Sommer, principal investigator

Mark A. Pollock
Temple University

James D. Savage
University of Virginia

Herbert W. Simons
Temple University

Techmonitor, Ltd.
Ron Johnston, principal investigator

---

[1] Part-time OTA senior analyst July-December 1990.

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CHAPTER 1

Summary and Issues for Congress

Introduction

Research provides extraordinary benefits to society through the creation of new knowledge and the training of scientists and engineers. The research and higher education system in the United States is the envy of the world, and has a long history of advancing the state of scientific knowledge. This is known as "scientific progress": ". . . not the mere accumulation of data and information, but rather the advancement of our codified understanding of the natural universe and of human behavior, social and individual."[1] These advances have addressed such goals as enhancing the Nation's public health, military security, prestige, educational achievement, work force, technological development, environmental quality, and economic competitiveness.

To say only that research contributes to national goals, however, simplifies and understates a complex system. Research is no longer a remote, scientist- or engineer-defined activity resulting in new knowledge for society. Perhaps it never was. "Deeply held political values of democratic accountability and public scrutiny have naturally and inevitably impinged on science policy. Demands for observable benefits from public investment in science increase."[2] Such demands have led to claims that scientific research has a significant and direct impact on the economy, and that an investment in knowledge is a downpayment on the products and processes that fuel U.S. economic growth and productivity.[3] Economists admit, however, that the difficulties in measuring the benefits of research ". . . are hard to exaggerate."[4] The Nation now expects that in addition to knowledge, science and engineering will contribute to U.S. prestige and competitiveness abroad, create new centers of research excellence on a broad geographic basis, continue to provide unparalleled opportunities for education and training, and nurture a more diverse research work force.

Photo credit: Research Triangle Institute

Scientists at the Research Triangle Institute, NC, synthesize chemicals for cancer research. Scientific research takes place in many settings in the United States.

Thus, the Federal Government funds research to achieve more than specific national goals. By doing so, it invests in knowledge—and the people who produce it—not only for its intrinsic worth (which can be considerable), but also for the value knowledge acquires as it is applied.

Scientific research is typically split into two categories, "basic" and "applied." Basic research pursues fundamental concepts and knowledge (theories, methods, and findings), while applied research focuses on the problems in utilizing these concepts and forms of knowledge. OTA does not generally distinguish between these categories in this report, because policymakers, especially Congress, make very few decisions in which the two are separate. In particular, research agency program managers rarely allocate monies on the basis of a project's basic or applied classification, and divisions of research funding into these categories are often unreliable.[5]

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[1] Harvey Brooks, "Knowledge and Action: The Dilemma of Science Policy in the 70s," *Daedalus*, vol. 102, spring 1973, p. 125. Unless otherwise stated, "science" in this report includes the social and behavioral sciences as well as the natural sciences and engineering. "Research" refers to a creative activity ongoing in all of these fields.

[2] Kenneth Prewitt, "The Public and Science Policy," *Science, Technology, & Human Values*, vol. 7, spring 1982, p. 13.

[3] See Edwin Mansfield, "The Social Rate of Return From Academic Research," *Research Policy*, forthcoming 1991; and James D. Adams, "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, vol. 98, No. 4, 1990, pp. 673-702.

[4] Quoted in Eugene Garfield, "Assessing the Benefits of Science in Terms of Dollars and Sense," *The Scientist*, vol. 4, No. 22, Nov. 12, 1990, p. 14. The source is Nathan Rosenberg and David C. Mowery, *Technology and the Pursuit of Economic Growth* (New York, NY: Cambridge University Press, 1989).

This Report and Its Origins

In December 1989, the House Committee on Science, Space, and Technology requested that OTA assist it in understanding the state of the federally funded research system—its goals, research choices, policies, and outcomes—and the challenges that it will face in the 1990s. By requesting a study of the state of the Nation's research system and of alternative approaches the Federal Government could take in funding research, the Committee sought information on the nature and distribution of research funding and decisionmaking. Direct congressional involvement in research decisionmaking is growing, and annual agency appropriations seem more closely tied to specific goals—and tough choices among them—than ever before.[6] As one member put it:

> . . . the payoffs for the Nation are so great that increased investments in science and technology are only prudent. However, even if we could double the science budget tomorrow, we would not escape the need to establish priorities. . . . [7]

The Federal Government has sustained an illustrious history of support for research. Underlying this relationship between government and the scientific community was a social contract or "trusteeship," developed after the scientific breakthroughs spurred by World War II, that delegated much judgment on Federal research choices to scientific experts.[8] Perhaps the epitome of the trusteeship was the research grant, which created a new relationship between the Federal Government and the research performer, especially the principal investigator in universities.[9] This social contract implied that in return for the privilege of receiving Federal support, the researcher was obligated to produce and share knowledge freely to benefit—in mostly unspecified and long-term ways—the public good.[10]

Since the 1960s, Federal funding for research (both basic and applied) has increased from roughly $8 billion in 1960 (1990 dollars) to over $21 billion in 1990 (see figure 1-1). Funding increased quickly in the early 1960s during the "golden years" for research, after the launch of the Sputnik satellite, the escalation of the Cold War, and the Presidential commitment to land men on the Moon. Once these challenges had been met, research funding decreased

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[5] A quarter-century ago it was noted that: "The precise partitioning of all basic research into components is, of course, largely arbitrary. Basic research can be classified in terms of its *motivation*—as culture, as an adjunct to education, as a means to accomplish nonscientific goals of the society; of its *sources of support*—whether mission-oriented agency or science-oriented agency; of its *performers*—whether university, government laboratory, or private industry; or of its *character*—whether 'little science' or 'big science.' Any one of these classifications, if applied consistently, cover all basic science, but none is wholly satisfactory. . . ." See National Academy of Sciences, Committee on Science and Public Policy, *Basic Research and National Goals*, A Report to the Committee on Science and Astronautics, U.S. House of Representatives (Washington, DC: March 1965), p. 9, italics added. This was independently confirmed by extensive OTA interviews with research agency personnel, spring-summer 1990. Today, research is also sometimes labeled "strategic," "targeted," or "precompetitive," for example. For an update and discussion, see Harvey Averch, "The Political Economy of R&D Taxonomies," *Research Policy*, forthcoming 1991.

[6] See National Academy of Sciences, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures* (Washington, DC: National Academy Press, 1989); and U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, *The Hearings on Adequacy, Direction and Priorities for the American Science and Technology Effort*, 101st Cong., Feb. 28-Mar. 1, 1989 (Washington, DC: U.S. Government Printing Office, 1989).

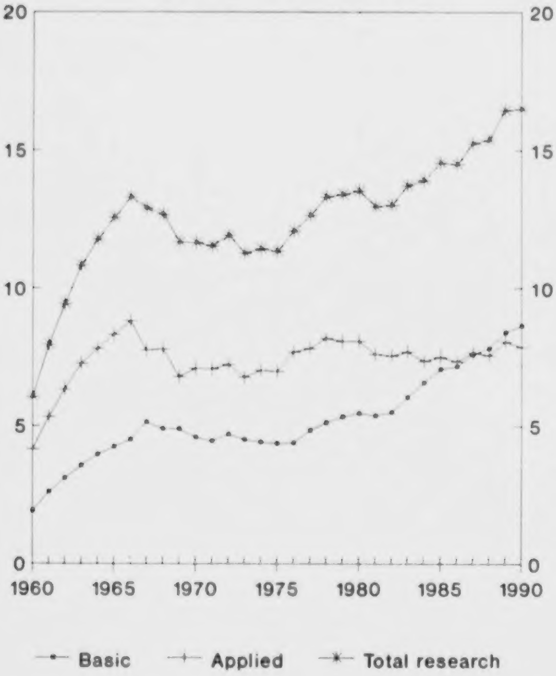
[7] Doug Walgren, Chairman of the House Subcommittee on Science, Research, and Technology, in House Committee on Science, Space, and Technology, op. cit., footnote 6, pp. 1-2.

[8] Research as a planned activity of the Federal Government can be traced to two landmark volumes: Vannevar Bush's 1945 "A Report to the President on a Program for Postwar Scientific Research" (subsequently known as *Science: The Endless Frontier*), which instigated the creation of an agency—the National Science Foundation—whose dual mission was the promotion of research and science education, and *Science and Public Policy*, or the 1947 Steelman Report, which championed a crosscutting policy role for managing federally funded research. For interpretations, see J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945-57* (Washington, DC: National Science Foundation, 1982); and Deborah Shapley and Rustum Roy, *Lost at the Frontier* (Philadelphia, PA: ISI Press, 1985).

[9] See U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, *A History of Science Policy in the United States, 1940-1985*, 99th Cong., September 1986 (Washington, DC: U.S. Government Printing Office, September 1986), pp. 19-20. Also see Rodney W. Nichols, "Mission-Oriented R&D," *Science*, vol. 172, Apr. 2, 1971, pp. 29-37.

[10] For examinations, see Bruce L.R. Smith, *American Science Policy Since World War II* (Washington, DC: The Brookings Institution, 1990), especially chs. 1 and 3; Gene M. Lyons, *The Uneasy Partnership: Social Science and the Federal Government in the Twentieth Century* (New York, NY: Russell Sage Foundation, 1969); and U.S. Congress, Office of Technology Assessment, *The Regulatory Environment for Science*, OTA-TM-SET-34 (Washington, DC: U.S. Government Printing Office, February 1986), pp. 15-16.

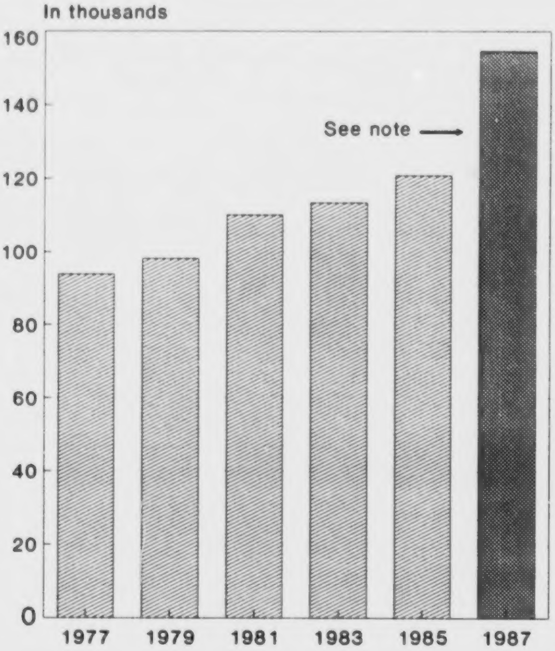
Figure 1-1—Federally Funded Research (Basic and Applied): Fiscal Years 1960-90
(in billions of 1982 dollars)



NOTE: Figures were converted into constant 1982 dollars using the GNP Implicit Price Deflator. For 1990 (current dollars), basic research = $11.3 billion, applied research = $10.3 billion, and total research = $21.7 billion. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1.

Figure 1-2—Doctoral Scientists and Engineers in Academic R&D: 1977-87



NOTE: There was a change in the wording of the National Science Foundation survey questionnaire of academic Ph.D.s in 1987: respondents were asked to identify whether "research" was their *primary or secondary* work activity. This change may have resulted in an artificially large increase from 1985 to 1987 in "academic researchers." Prior to 1987, Ph.D.s in academia were only asked to identify their *primary* work activity.

SOURCE: National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), appendix table 5-17 and p. 115.

slightly and leveled off from the late 1960s until the mid-1970s. From 1975 onward, however, Federal research funding again increased, due in large part to the expansion in health and life sciences research.[11]

Along with this increase in research funding, the number of academic researchers grew steadily, perhaps by as much as 60 percent from 1977 to 1987 (see figure 1-2).[12] More generally, from 1980 to 1988, scientists and engineers in the work force grew by an average of 7.8 percent per year, four times the annual rate for total employment.[13] Not surprisingly, the competition for research funds among these scientists and engineers also intensified. By the late

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[11] See National Science Foundation, *Federal Funds for Research and Development—Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990). For discussions, see William D. Carey, "R&D in the Federal Budget: 1976-1990," *Science and Technology and the Changing World Order*, Colloquium Proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), pp. 43-51; and Genevieve J. Knezo, "Defense Basic Research Priorities: Funding and Policy Issues," *CRS Report for Congress* (Washington, DC: Oct. 24, 1990).

[12] Note, however, that there was a change in the wording of the National Science Foundation survey questionnaire, which may have resulted in an artificially large increase from 1985 to 1987 in those that identify "research" as their primary or secondary work activity. Prior to 1987, Ph.D.s in academia were only asked to identify their *primary* work activity. This probably underestimated the number of academic Ph.D. researchers in the United States. See National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: Congressional Research Service, 1989), app. table 5-17.

[13] Ibid., p. 67.

1980s, researchers supported by the Federal Government had become increasingly restive over funding. Today, many say that their lives as researchers have become more stressful and laden with the paperwork of proposal applications and accountability for awarded funds, inhibiting the creativity and joy of the research process.[14] They cite the declining fraction of meritorious proposals that are funded, new investigators lacking the support to set up independent research groups, and the fear that U.S. students will turn their careers away from academic science and engineering.[15]

Today, because the scientific community has the capability to undertake far more research than the Federal Government supports, policymakers and sponsors of research must continuously choose between competing ''goods.'' (The tensions underlying these choices are summarized in table 1-1.) Controversies over the support of younger scientists and established researchers, ''have'' and ''have-not'' institutions, and tradeoffs among fields are all manifestations of the consequences of choices perceived by various segments of the ''scientific community.''[16] Scientific community, as used here, refers to a political entity. Like other sectors, science contributes to national goals and competes for Federal resources. At a more practical level, *the* scientific community invoked by Congress and the Presidential Science Advisor refers to a heterogeneity of professional associations, lobby activities, and actual research performers. (These disciplinary or subject-specific divisions and interest groups more accurately correspond to what OTA calls ''research communities.'')

Additional funding for science and engineering research would certainly be a good investment of Federal resources. There is much that could be done, and many willing and able people and institutions to do it. The focus of this report, however, is not on the level of investment, but on the ''Federal research system.'' As the sum of the research programs and efforts that involve the support of the Federal Government, the ''system'' is best characterized as the conglomeration of many separate systems, each with constituencies inside and outside of science.[17] *How* these participants compete, cooperate, and interact in processes of Federal decisionmaking determines *which* research is funded by the agencies and performed by scientists and engineers.

If large increases in the budget were to materialize, it would not necessarily relieve system stresses for long. Additional research funding would certainly allow the pursuit of more scientific opportunities and yield fruitful gains, but it would also enlarge the system and increase the number of deserving competitors for Federal support. Thus, such stresses must be addressed with other policies. In the short term, the government faces a rising budget deficit. Congress has set targets to reduce the deficit and eventually to balance the budget.[18] In this fiscal climate, the research system may not be able to maintain the growth in Federal funding of research that it experienced in the 1980s. Regardless of funding levels, however, issues of management, funding, and personnel remain.

Given the extraordinary strength of the U.S. research system and the character of scientific research, there will always be more opportunities

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[14] *Science: The End of the Frontier?* A report from Leon M. Lederman, President-Elect to the Board of Directors of the American Association for the Advancement of Science (Washington, DC: American Association for the Advancement of Science, Jan. 31, 1991).

[15] These were the prominent issues, for example, at the National Academy of Sciences/Institute of Medicine, ''Forum on Supporting Biomedical Research: Near-Term Problems and Options for Action,'' Washington, DC, June 27, 1990. Recent discussion has paradoxically focused on the broad field of the life sciences where Federal funding increases have been most generous for the last 15 years. In its initial effort to document change and stress in the Federal research system created by an abundance of research applications, OTA found that an increasing proportion could not be funded by various research agencies due to budget limitations, rather than to deficiencies of quality. U.S. Congress, Office of Technology Assessment, ''Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System,'' staff paper of the Science, Education, and Transportation Program, April 1990.

[16] See Institute of Medicine, *Funding Health Sciences Research: A Strategy to Restore Balance* (Washington, DC: National Academy Press, November 1990). For insight into the contentiousness that greeted the Institute of Medicine report, see Peter G. Gosselin, ''A Clash of Scientific Titans: Key Groups Battle Over Funds for Medical Projects,'' *The Washington Post*, Dec. 18/25, 1990, Health section, p. 6.

[17] As one political scientist writes: ''. . . because the Federal R&D system is comprised of so many independent actors, each of whom tend to view science and engineering from a relatively narrow perspective, the Federal R&D system proceeds virtually without planning and coordination. If it moves . . . it does so . . . oozing slowly and incrementally in several directions at once, with constantly changing boundaries and shape.'' Joseph G. Morone, ''Federal R&D Structure: The Need for Change,'' *The Bridge*, vol. 19, fall 1989, p. 6.

[18] The debt held by the Federal Government recently topped $3.1 trillion, and payments on the debt exceeded $255 billion in fiscal year 1990. These figures are expected to rise significantly in 1991 and 1992, with the costs of the war in the Persian Gulf and the bailouts of the Nation's financial system. For an explanation of the Budget Enforcement Act of 1990, see Lawrence J. Haas, ''New Rules of the Game,'' *National Journal*, vol. 22, No. 46, Nov. 17, 1990, pp. 2793-2797.

Table 1-1—Tensions in the Federal Research System

Centralization of Federal research planning	←→	Pluralistic, decentralized agencies
Concentrated excellence	←→	Regional and institutional development (to enlarge capacity)
"Market" forces to determine the shape of the system	←→	Political intervention (targeted by goal, agency, program, institution)
Continuity in funding of senior investigators	←→	Provisions for young investigators
Peer review-based allocation	←→	Other funding decision mechanisms (agency manager discretion, congressional earmarking)
Set-aside programs	←→	Mainstreaming criteria in addition to scientific merit (e.g., race/ethnicity, gender, principal investigator age, geographic region)
Conservatism in funding allocation	←→	Risk-taking
Perception of a "total research budget"	←→	Reality of disaggregated funding decisions
Dollars for facilities or training	←→	Dollars for research projects
Large-scale, multiyear, capital-intensive, high-cost, per-investigator initiatives	←→	Individual investigator and small-team, 1-5 year projects
Training more researchers and creating more competition for funds	←→	Training fewer researchers and easing competition for funds
Emulating mentors' career paths	←→	Encouraging a diversity of career paths
Relying on historic methods to build the research work force	←→	Broadening the participation of traditionally underrepresented groups

SOURCE: Office of Technology Assessment, 1991.

than can be funded, more researchers competing than can be sustained, and more institutions seeking to expand than the prime sponsor—the Federal Government—can fund. The objective, then, is to ensure that the best research continues to be funded, that a full portfolio of research is maintained, and that there is a sufficient research work force of the highest caliber to do the job. This report is designed to support Congress in achieving these goals.

Trends in Federal Research Funding

The research system has shown itself to be remarkably robust over at least the last 30 years, and it has done well with the resources it has received. To develop multiple perspectives on the system, Federal funding can be examined by agency, broad field, and category of recipient.

Figure 1-3 displays Federal funding trends for the six largest research agencies.[19] Since 1973, the Department of Health and Human Services (HHS, largely through the National Institutes of Health—NIH) has supported more research than any other Federal research agency. In fiscal year 1989, HHS supplied nearly twice the research funds of the next largest research agency, the Department of Defense (DOD). HHS and DOD were followed by the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the National Science Foundation (NSF), and the Department of Agriculture (USDA).[20]

Reflecting the division of research funds by agency and broad field, a 20-year time series is shown in figure 1-4. Life sciences continues its steady growth relative to other broad fields. In fiscal year 1990, life sciences dominated Federal funding at $8.9 billion (in 1990 dollars). Engineering was funded at slightly less than one-half the level of support given to the life sciences ($4.4 billion), as were the physical sciences (roughly $4 billion). Environmental and mathematics/computer sciences were funded at $2.1 and $0.7 billion respectively, and the social sciences together gathered $0.6 billion.

Turning to research performance, universities and colleges in the aggregate are the largest recipients of federally funded research (basic and applied, see

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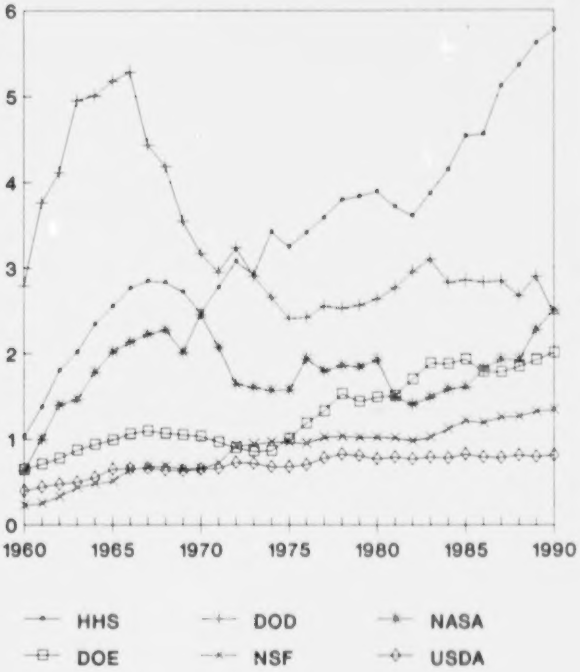
[19] Congress is most interested in comparing research expenditures to other elements of the Federal budget. Thus, a deflator that represents expenditures on products and services that are often bought throughout the United States—a "constant dollar" in the most general sense—is often the most useful for congressional policy analysis. Given the problems with research-specific deflators and the advantage of a general-GNP deflator to compare expenditures across the economy, all constant dollar graphs and tables in this report were calculated with the GNP Implicit Price Deflator for 1982 dollars (see ch. 2).

[20] Note that the order of these agencies would be changed if research and development or basic research were used to rank them. The remaining agencies, not included in the top six, together fund less than 5 percent of the research supported by the Federal Government.

Figure 1-3—Federally Funded Research in the Major Research Agencies: Fiscal Years 1960-90 (in billions of 1982 dollars)



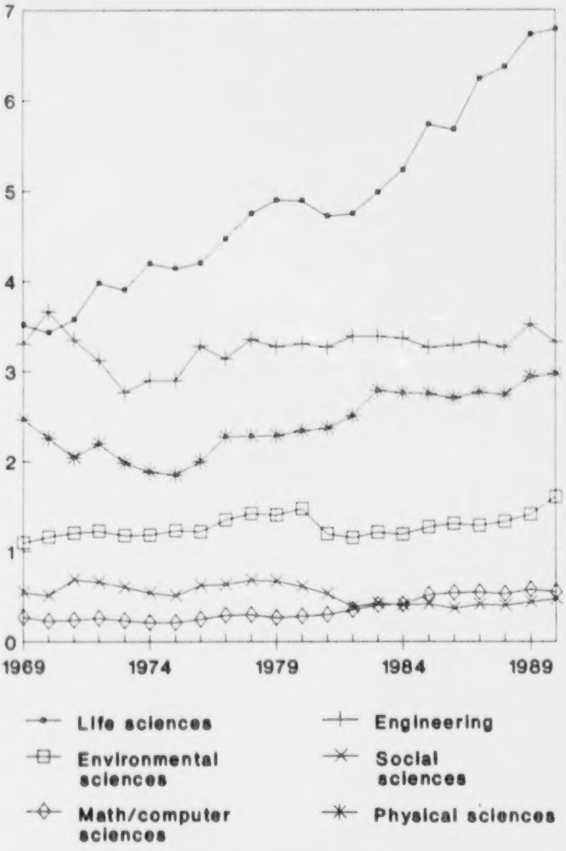
KEY: HHS=U.S. Department of Health and Human Services; DOD=U.S. Department of Defense; NASA=National Aeronautics and Space Administration; DOE=U.S. Department of Energy; NSF=National Science Foundation; USDA=U.S. Department of Agriculture.

NOTE: Research includes both basic and applied. Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

figure 1-5). From 1969 to 1990, Federal funding for research at universities and colleges grew from over $4 billion to nearly $8 billion (in constant 1990 dollars). In 1990, performance of research by industry (at over $3 billion) and the Federal laboratories (at over $6 billion) are funded at lower levels. For basic research alone (not shown), universities and colleges are even more clearly the dominant research performer at over $5 billion when compared with Federal laboratories, the next largest basic research performer, at slightly over $2 billion.

Figure 1-4—Federally Funded Research by Broad Field: Fiscal Years 1960-90 (in billions of 1982 dollars)

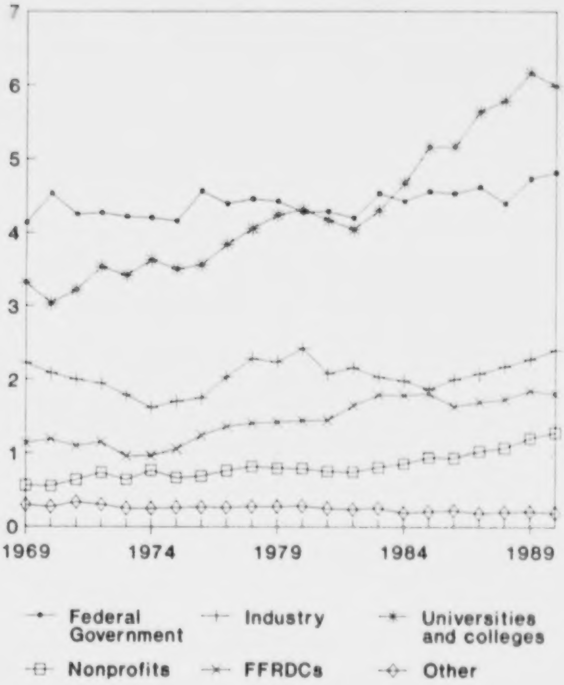


NOTE: Research includes both basic and applied. Fields not included in this figure collectively accounted for $1.1 billion (4.9 percent) of all federally funded research in 1990. Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table 25; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1.

The distribution of Federal research and development (R&D) funds has long been a contentious issue—both in Congress and in the scientific community. As shown in figure 1-6, if these funds are aggregated by the State of the recipient institution or laboratory, then five States received 53 percent of the R&D funds in fiscal year 1990 (California,

Figure 1-5—Federally Funded Research by Performer: Fiscal Years 1969-90 (in billions of 1982 dollars)



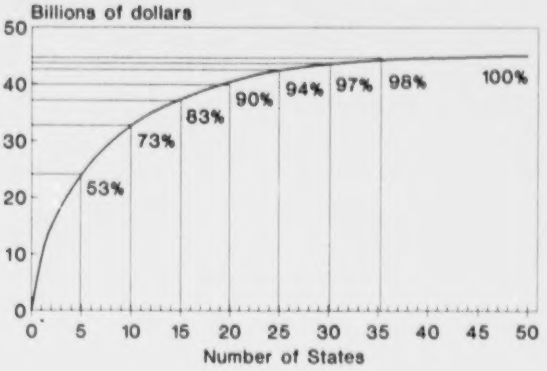
KEY: FFRDCs include all Federally Funded Research and Development Centers that are not administered by the Federal Government. Other includes Federal funds distributed to State and local governments and foreign performers.

NOTE: Research includes both basic and applied. Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

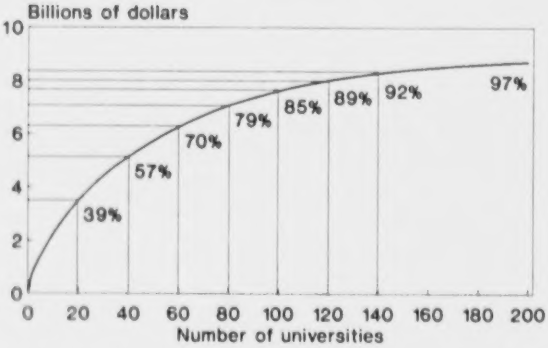
SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table 17; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1.

Figure 1-6—Federal R&D Obligations by State (1985) and at Universities and Colleges (1989)

Cumulative distribution of Federal R&D obligations by State: 1985



Cumulative distribution of Federal R&D expenditures at universities and colleges: 1989



SOURCE: National Science Foundation, *Geographic Patterns: R&D in the United States*, Final Report, NSF 90-316 (Washington, DC: 1990), table B-5; and National Science Foundation, *Selected Data on Academic Science/Engineering R&D Expenditures, Fiscal Year 1989*, NSF 90-321 (Washington, DC: October 1990), table B-35 and CASPAR database.

Maryland, Massachusetts, New York, and Virginia).[21] (Research institutions are also not randomly dispersed across America; rather, they are concentrated on the two coasts and the upper midwest.) At the other end of the distribution, 15 States together received less than 2 percent of the funds. At the institutional level, 10 universities receive 25 percent of the Federal research funding, and only 30 universities account for 50 percent. Funding is concentrated in 100 research universities in 38 States. This reflects their importance to the Nation's research enterprise.

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[21] These figures are presented for research and development, because figures for research alone are not available. Based on 1984 data, the General Accounting Office found various patterns of concentration among performers: researchers in 10 States submitted over one-half of the proposals to the National Science Foundation and the National Institutes of Health, supplied almost 60 percent of the proposal reviewers, and won over 60 percent of the awards. See U.S. General Accounting Office, *University Funding: Patterns of Distribution of Federal Research Funds to Universities* (Washington, DC: February 1987), p. 43. These figures, however, ignore other relevant factors in judging the "fair" distribution of Federal research funds, such as the total population of a State and the number of scientists and engineers living in it. No matter how fair the competitive process, the outcomes may still be seen as "unfair." Also see William C. Boesman and Christine Matthews Rose, "Equity, Excellence, and the Distribution of Federal Research and Development Funds," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Apr. 25, 1989).

These data on the distribution of resources bear a critical message: research capabilities—institutions and people—take time to grow. It is not simply a matter of "they who have, get." The reputation, talent, and infrastructure of research universities attract researchers and graduate students.[22] Some universities become assets not only in the production of fundamental knowledge, but also in bridging science and technology to other goals such as State and regional economic development.

Federally Funded Research in the 1990s

Snapshots of federally funded research, comparing fiscal years 1980 and 1991, are provided in table 1-2. Research is a small portion of the total Federal budget. Although the distribution of research funds by agency sponsor, category of performer, and stratum of academic institution has hardly changed during this period, the activity has never been in greater demand.

However, questions such as "Does the Nation need more science?" and "How much research should the Federal Government support?" have no ready answers. Measures of distress and conflicts over resource allocation within the scientific community do not address whether the Nation needs more science. Other problems in the Federal research system do not derive from, but are exacerbated by, such stress. They include sparse participation by women and ethnic minorities in science, indications that other nations are better able to capitalize on the results of U.S. research than American industry, and management problems that have plagued many Federal research agencies. Only some of these problems can be addressed solely by the Federal Government, and long-term solutions may not be found in adjusting Federal funding levels. Rather, they reflect problems in the organization and management of research and competing values within the scientific community.[23]

"How much is enough" depends on the goals of the research system (see box 1-A). The system by definition takes on new goals, each of which can be evaluated. But in the aggregate how these goals are assimilated—by add-on or substitution—is not easily predicted. The challenge is not to determine what fraction of the Federal budget would constitute appropriate funding for scientific research. Rather, **OTA finds that under almost any plausible scenario for the level of research funding in the 1990s, there are issues of planning, management, and progress toward national goals to address.**

Because the reach of science is now great, decisions about the funding of research are intertwined with many Federal activities. Congress and the executive branch, which make these decisions in our form of government, will continue to wrestle with scientific and other national priorities, especially those that help prepare for tomorrow's science—renewing human resources throughout the educational pipeline and building regional and institutional capacity. History cautions against the expectation that the scientific community will set priorities across fields and research areas. Congress must instead weigh the arguments made within each area against desired national outcomes.

In the 1990s, the Federal research system will face many challenges. OTA has organized them here under four interrelated issues: 1) setting priorities for the support of research; 2) understanding research expenditures; 3) adapting education and human resources to meet the changing needs of the research work force; and 4) refining data collection, analysis, and interpretation to improve Federal decisionmaking. (For a summary of issues and possible congressional responses, see table 1-3.) To craft public policies for guiding the system, each issue is outlined in the following discussion.

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[22] Institutions, like the faculty researchers employed by them, accumulate "advantage." Among the many factors that influence Federal research funding, institutional reputation is part of a cycle of credibility that gives investigators an edge in competition for scarce resources—the very resources that strengthen the institution as a productive research performer, which builds more credibility, and so on. See Robert K. Merton, "The Matthew Effect in Science, II: Cumulative Advantage and the Symbolism of Intellectual Property," *Isis*, vol. 79, No. 299, 1988, pp. 606-623.

[23] See Joshua Lederberg, "Does Scientific Progress Come From Projects or People?" *Current Contents*, vol. 29, Nov. 27, 1989, pp. 4-12. In this report, OTA concentrates on Federal, especially agency, perspectives on research. Performer (researcher and institutional) responses to changes in Federal policies and programs were included to broaden understanding of the Federal role vis-a-vis *academic* research, since universities are the primary site for research performance and most data are collected on universities. However, national laboratories and industry play targeted roles and figure prominently in research funding decisions.

Table 1-2—Federally Funded Research in the 1980s and 1990s (In percent)

		Fiscal year 1980	Fiscal year 1991 (est.)
R&D as percent of total Federal budget		5.0	4.7
Total research as percent of Federal R&D		38.9	36.3
Basic research as percent of Federal R&D		15.7	19.1
Basic research as percent of total Federal budget		0.8	0.9
	Agency	Fiscal year 1980	Fiscal year 1991 (est.)
Percent of total (basic) research funds distributed, by agency	HHS/NIH	29/24 (38/35)	34/29 (40/37)
	DOD	20 (12)	15 (8)
	NASA	14 (12)	16 (15)
	DOE	11 (11)	12 (14)
	NSF	8 (17)	9 (15)
	USDA	6 (6)	5 (5)
	Other	7 (4)	10 (4)
	Performer	Fiscal year 1980	Fiscal year 1991 (est.)
Percent of total (basic) research funds, by performer	Universities	32 (50)	36 (47)
	Federal	32 (25)	30 (23)
	Industry	18 (7)	15 (9)
	Nonprofits	6 (6)	8 (9)
	FFRDCs[a]	11 (11)	11 (12)
	Ranking	Fiscal year 1980	Fiscal year 1988
Percent distribution of Federal R&D funds at academic institutions	Top 10	25	25
	Top 20	40	39
	Top 50	68	65
	Top 100	84	85

KEY: DOD=U.S. Department of Defense; DOE=U.S. Department of Energy; FFRDC=Federally Funded Research and Development Center; USDA=U.S. Department of Agriculture; NSF=National Science Foundation; HHS/NIH=U.S. Department of Health and Human Services/National Institutes of Health; NASA=National Aeronautics and Space Administration

[a] The category of FFRDCs includes all Federally Funded Research and Development Centers that are *not* administered by the Federal Government.

NOTE: R&D data are based on Federal obligations; calculations involving the total Federal budget are based on outlays. Columns may not sum to 100 percent due to rounding.

SOURCES: Office of Technology Assessment, 1991, based on National Science Foundation data; U.S. General Accounting Office data; *Economic Report of the President* (Washington, DC: U.S. Government Printing Office, 1991); and *Budget of the United States Government: Fiscal Year 1992* (Washington, DC: U.S. Government Printing Office, 1991).

Issues and Options for Congress

ISSUE 1: Setting Priorities in the Support of Research

Summary

Priorities are set throughout the Federal Government at many levels. At the highest level, research priorities are compared to nonscience and nonengineering needs. At the next level, priorities are set across research fields, such as biomedicine and mathematics. Within fields, agency programs reflect research opportunities in subfields and relevance to national needs. Finally, research projects are compared, ranked, and awarded Federal funds.

Although priority setting occurs throughout the Federal Government, it falls short in three ways. First, criteria used in selecting various areas of research and megaprojects are not made explicit and vary widely from area to area. This is particularly true, and particularly a problem, at the highest levels of priority setting, e.g., in the President's budget and the congressional decision process. Second, there is currently no mechanism for evaluating the total research portfolio of the Federal Government in terms of progress toward many national objectives, although recent efforts by the Office of Science and Technology Policy have lead to some cross-agency planning, budgeting, and evaluation. Third, the principal criteria for selection, scientific merit and mission relevance, are in practice coarse filters. Con-

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Box 1-A—How Much is Enough?

"How much is enough money for research?" is a question that can only be asked if it is clear what scientific and engineering research in the United States is attempting to accomplish: research for what?

1. Is the primary goal of the Federal research system to fund the projects of all deserving investigators of natural and social phenomena?
   If so, then there will always be a call for more money, because research opportunities will always outstrip the capacity to pursue them.
2. Is it to educate the research work force, or the larger science and engineering work force, needed to supply the U.S. economy with skilled labor?
   If so, then support levels can be gauged by the need for more technically skilled workers. Preparing students throughout the educational pipeline will assure an adequate supply and diversity of talent.
3. Is it to promote economic activity and build research capacity throughout the United States economy by supplying new ideas for industry and other entrepreneurial interests?
   If so, then the support should be targeted in line with our efforts to pursue applied research, development, and technology transfer.
4. Is it all of the above and other goals besides?
   If so, then some combination of these needs must be considered in allocating Federal support.

Indicators of stress and competition in the research system do not address the question of whether science needs more funding to do more *science*. Rather, they speak to the organization and processes of science and to the competitive foundation on which the system is built and that sustains its vigor.

Education, economic activity, and other national goals have long been confronted by Congress and the executive branch. Although the relative importance of these needs varies over time with new developments and crises, their absolute importance has not been set. Thus, allocating resources to these needs has always been a tradeoff, within a limited budget, against other national goals and the programs that embody them.

Because of its intrinsic merit and importance to the Nation, research has consistently been awarded funding increases. But these do not compare to what some claim would be an appropriate level of funding for research to pursue a full agenda of opportunities. Deciding if the Nation is pursuing enough research opportunities or if the Nation needs more science is thus a complicated question, which requires that other decisions about the nature of the research system and its goals be settled first. Table 1A-1 reports the costs of some potential science initiatives as estimated in the late 1980s.

Table 1A-1—Sample Requests From the Research Community for Increased Funding

Field or agency	Report or intiative	Additional funds requested[a]
NSF	Initiative to double the NSF budget	$2.1 billion
NASA space science	Towards a New Era in Space: Realigning U.S. Policies to New Realities[b]	Over $1 billion
Neuroscience	1990s Decade of the Brain Initiative[c]	Over $1 billion
USDA research grants	Investing in Research[d]	$0.5 billion
Behavioral and social sciences	The Behavioral and Social Sciences: Achievements and Opportunities[e]	$0.26 billion
Mathematical sciences	Renewing U.S. Mathematics[f]	$0.12 billion
All academic research	Science: The End of the Frontier?[g]	Over $10 billion

KEY: NSF=National Science Foundation; NASA=National Aeronautics and Space Administration; USDA=U.S. Department of Agriculture

[a] Adjusted to 1990 dollars using the 1982 GNP Implicit Price Deflator.

[b] National Academy of Sciences/National Academy of Engineering, Committee on Space Policy, "Towards a New Era in Space: Realigning U.S. Policies to New Realities," *Space Policy*, vol. 5, August 1989, pp. 237-255.

[c] " 'Brain Decade' Neuroscientists Court Support," *The Scientist*, vol. 4, No. 21, Oct. 29, 1990, p. 8.

[d] National Research Council, *Investing in Research* (Washington, DC: National Academy Press, 1989).

[e] National Research Council, *The Behavioral and Social Sciences: Achievements and Opportunities* (Washington, DC: National Academy Press, 1988).

[f] National Research Council, *Renewing U.S. Mathematics: A Plan for the 1990s* (Washington, DC: National Academy Press, 1990).

[g] *Science: The End of the Frontier?* a report from Leon M. Lederman, President-Elect to the Board of Directors of the American Association for the Advancement of Science (Washington, DC: American Association for the Advancement of Science, Jan. 31, 1991).

SOURCE: Office of Technology Assessment, 1991.

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Table 1-3—Summary of Issues and Possible Congressional Responses

Issue	Possible congressional responses
Setting priorities for research	Hearings on crosscutting priorities and congressional designation of a body of the Federal Government to evaluate priority setting. Application of criteria to: a) promote education and human resources, b) build regional and institutional capacity in merit-based research decisionmaking, and c) balance little science and megaproject initiatives. Oversight of agency research programs that focuses on strategies to fulfill the above criteria, and on responses to priority setting.
Coping with changing expenditures for research	Encouragement of greater cost-accountability by the research agencies and research performers (especially for indirect costs, megaprojects, and other multiyear initiatives). Allowance for the agencies to pursue direct cost containment measures for specific items of research budgets and to evaluate the effectiveness of each measure.
Adapting education and human resources to meet future needs	Programs that focus investment on the educational pipeline at the K-12 and undergraduate levels. Attention to diversity in the human resource base for research, especially to the contributions of underparticipating groups. Incentives for adapting agency programs and proposal requirements to a changing model of research (where teams are larger, more specialized, and share research equipment and facilities).
Refining data collection and analysis to improve research decisionmaking	Funding to: a) augment within-agency data collection and analysis on the Federal research system, and b) increase use of research program evaluation at the research agencies. Encouragement of data presentation and interpretation for use in policymaking, e.g., employing indicators and other techniques that measure outcomes and progress toward stated objectives.

SOURCE: Office of Technology Assessment, 1991.

cerns for developing human resources and building regional and institutional capacity must also be considered; these criteria strengthen future research capability. While not every project or agency will factor these criteria equally, the total Federal research portfolio must address these concerns.

Priority-setting mechanisms that cut across research fields and agencies, and that make selection criteria more transparent, must be strengthened in both Congress and the executive branch. Congressional oversight must evaluate the total Federal research portfolio based on national objectives, research goals, and agency missions. In the executive branch, Congress should insist, at a minimum, on iterative planning that results in: a) setting priorities among research goals, and b) applying (after scientific merit and program relevance) other criteria to research decisionmaking that reflect planning for the future. In addition, since megaproject costs affect the ability of other disciplines to start new, large projects, megaprojects are candidates for crosscutting priority setting.

Discussion

Priority setting can help to allocate Federal resources both when they are plentiful, as they were in the 1960s, and when they are scarce, as expected through the early 1990s.[24] Governance requires that choices be made to increase the benefits and decrease the risks to the Nation. Priority setting occurs throughout the Federal Government at many levels. At the highest level, research priorities are compared to nonscience and nonengineering needs. At the next level, priorities are set across research fields, such as biomedicine and mathematics. Within fields, agency research programs reflect research opportunities in subfields and relevance to national needs. Finally, research projects are compared, ranked, and awarded Federal funds.

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[24] Congress recognized the importance of priority setting in the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282), May 11, 1976. For an elucidation of the dilemmas inherent in priority setting, especially comparisons between "social merit" and "scientific merit," see A.M. Weinberg, *Reflections on Big Science* (Cambridge, MA: MIT Press, 1966). Also see Stephen P. Strickland, *Research and the Health of Americans* (Lexington, MA: Lexington Books, 1978).

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Photo credit: Department of Energy

Underground nuclear test craters dot Yucca Flat at the Nevada Test Site (NTS). In addition to nuclear testing, researchers at NTS explore other scientific phenomena, such as geologic and seismic problems.

Toward More Explicit Priority Setting

There are three problems with priority setting as it is currently practiced in the Federal Government. First, criteria used in selecting various areas of research and megaprojects are not made explicit, and vary widely from area to area. This is particularly true, and particularly a problem, at the highest levels of priority setting—e.g., in the President's budget and the congressional decision process. The best developed priority-setting mechanisms are within the research agencies and at the agency program level.

Second, there is currently no mechanism for evaluating the total research portfolio of the Federal Government in terms of progress toward many national objectives. Research priorities must be considered across the Federal research system, and in particular, across the Federal agencies. What the Federal Government values more or less in research can be inferred in part from the Federal budget, but there is no "research budget." Federal support is distributed across many executive agencies and falls under the jurisdiction of a number of congressional committees and subcommittees (see table 1-4). Therefore, once allocations have been made to agencies (by the Office of Management and Budget—OMB) or to appropriations subcommittees (by full appropriations committees), decisions are made independently within narrow components of what is after-the-fact called the research budget. This hampers the implementation of crosscutting comparisons by Congress.

During the 1980s, OMB was a surrogate for a crosscutting agent, with Congress adding its own priorities through budget negotiations.[25] Recent efforts by the Office of Science and Technology Policy (OSTP) have lead to cross-agency planning, budgeting, and evaluation in certain research and education areas. President Bush has invested more power in OSTP to participate with OMB in deliberations over research spending, especially in targeted

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[25] For an overview, see Elizabeth Baldwin and Christopher T. Hill, "The Budget Process and Large-Scale Science Funding," *CRS Review*, February 1988, pp. 13-16.

Table 1-4—Congressional Authorization Committees and Appropriations Subcommittees With Significant Legislative Authority Over R&D

Jurisdictions of authorization committees: [a]	Agency
House:	
Agriculture	USDA
Armed Services	DOD, DOE
Energy and Commerce	DOE, ADAMHA, NIH, CDC, DOT
Interior and Insular Affairs	DOI
Science, Space, and Technology	NASA, NSF, DOE, EPA, NOAA, DOT, NIST, DOI
Public Works and Transportation	NOAA, DOT
Merchant Marine and Fisheries	USDA, NOAA, DOT
Veterans' Affairs	VA
Foreign Affairs	A.I.D.
Senate:	
Agriculture, Nutrition, and Forestry	USDA
Armed Services	DOD, DOE
Commerce, Science, and Transportation	NSF, NASA, DOT, NOAA, NIST
Energy and Natural Resources	DOE, DOI
Labor and Human Resources	NIH, ADAMHA, CDC, NSF
Environment and Public Works	EPA
Veterans' Affairs	VA
Foreign Relations	A.I.D.

Jurisdictions of appropriations committees: [a]	Agency
Labor, Health and Human Services, Education and Related Agencies	NIH, ADAMHA, CDC
HUD and Independent Agencies	NASA, NSF, EPA, VA
Energy and Water Development	DOE
Interior and Related Agencies	DOE, USDA, DOI
Agriculture, Rural Development, and Related Agencies[b]	USDA
Commerce, Justice, State, the Judiciary, and Related Agencies	NOAA, NIST
Transportation and Related Agencies	DOT
Foreign Operations	A.I.D.
Defense	DOD

KEY: ADAMHA=Alcohol, Drug Abuse, and Mental Health Administration; A.I.D.=Agency for International Development; CDC=Centers for Disease Control; DOD=U.S. Department of Defense; DOE=U.S. Department of Energy; DOI=U.S. Department of the Interior; DOT=U.S. Department of Transportation; EPA=U.S. Environmental Protection Agency; HUD=U.S. Department of Housing and Urban Development; NASA=National Aeronautics and Space Administration; NIH=National Institutes of Health; NIST=National Institute of Standards and Technology; NOAA=National Oceanographic and Atmospheric Administration; NSF=National Science Foundation; USDA=U.S. Department of Agriculture; VA=U.S. Department of Veterans Affairs.

[a] The jurisdictions of the authorizing committees are not exclusive. For this table, repeated authorization of a number of R&D-related programs was required to establish jurisdiction.

[b] The corresponding subcommittees of the Senate and House Committees on Appropriations have the same name with one exception: the Senate Subcommittee on Agriculture, Rural Development, and Related Agencies and the House Subcommittee on Rural Development, Agriculture, and Related Agencies.

SOURCES: Office of Technology Assessment, 1991; and Elizabeth Baldwin and Christopher T. Hill, "The Budget Process and Large-Scale Science Funding," *CRS Review*, February 1988, p. 15.

Presidential priority areas such as high-performance computing, global environmental change, and mathematics and science education.[26] Since the Administration is moving in the direction of more centralized and coordinated priority setting, it is all the more important for Congress to consider priority-setting mechanisms as well.

Third, although scientific merit and mission relevance must always be the chief criteria used to judge a research area or agency program's potential worth, they cannot always be the *sole* criteria. In particular, the application of criteria that augment scientific merit—which represent *today's* judgments of quality—would help meet *tomorrow's*

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[26] The clearest public statement of executive branch priorities is contained in "Enhancing Research and Expanding the Human Frontier," *Budget of the United States Government, Fiscal Year 1992* (Washington, DC: U.S. Government Printing Office, 1991), pp. 35-76. The ground rules for setting crosscutting priorities through the Office of Science and Technology Policy, Federal Coordinating Council on Science, Engineering, and Technology Committee mechanism are detailed in the Office of Management and Budget (OMB) "terms of reference" memoranda (provided to OTA project staff during an interview with Robert E. Grady, Associate Director, Natural Resources, Energy, and Science, and other OMB staff, Feb. 7, 1991.

Box 1-B—Criteria for Research Decisionmaking in Agency Programs

Within agency research programs, research proposals have traditionally been selected for support on the basis of expert peer or program manager judgments of "scientific merit" and program relevance. Many Federal agencies are now finding that the introduction of other explicit criteria is important for research decisionmaking.[1]

For example, the National Science Board (NSB) established the following criteria for the selection of research projects by the National Science Foundation (NSF): 1) research performer competence, 2) intrinsic merit of the research, and 3) utility or relevance of the research. In addition, NSB included 4) the ". . . effect of the research on the infrastructure of science and engineering. This criterion relates to the potential of the proposed research to contribute to better understanding or improvement of the quality, distribution, or effectiveness of the Nation's scientific and engineering research, education, and manpower base."[2]

Under this fourth criterion, NSF includes:

> . . . questions relating to scientific, engineering, and education personnel, including participation of women, minorities, and disabled individuals; the distribution of resources with respect to institutions and geographical area; stimulation of high quality activities in important but underdeveloped fields; support of research initiation for investigators without previous Federal research support as a Principal Investigator or Co-Principal Investigator; and interdisciplinary approaches to research or education in appropriate areas.[3]

In short, this criterion defines the bases for using other criteria in addition to scientific merit in mainstream allocations of research funds, and within set-aside programs. Set-aside programs, at NSF and elsewhere, underscore the continuing need for "sheltered competitions" for researchers who do not fare well in mainstream disciplinary programs.[4]

As acknowledged by NSB, although scientific merit and program relevance must always be the primary criteria used to judge a research program or project's potential worth, they cannot always be the only criteria. For most of today's research programs, there are many more scientifically meritorious projects than can be funded. Proposal

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[1] OTA interviews, spring-summer 1990.

[2] Quoted in National Science Foundation, *Grants for Research and Education in Science and Engineering: An Application Guide*, NSF 90-77 (Washington, DC: August 1990), pp. 8-9.

[3] Ibid., p. 9.

[4] OTA finds that, in some programs at the National Science Foundation (NSF), the fourth criterion is not strongly heeded relative to the other three criteria in the merit review process (OTA interviews, spring-summer, 1990). NSF faces the impossible task of being all things to all people. The organic act entrusts it with the support of the Nation's basic research and science education. In the academic institutions that form NSF's core clientele these activities are not pursued in the same way or with the same vigor. Every research program at NSF now impacts on human resources for science and engineering. This should remain foremost in mind when weighing policies for research programs.

objectives of research investment. Broadly stated, there are two such criteria: strengthening education and human resources at all stages of study (e.g., increasing the diversity and versatility of participants); and building regional and institutional capacity (including economic development by matching Federal research support with funds from State, corporate, and nonprofit sources).

Education and human resources criteria would weigh research initiatives on their "production" of new researchers or technically skilled students. Contributions to human resources include increasing participation in the educational pipeline (through degree completion), the research work force, and the larger science and engineering work force. Regional and institutional capacity criteria would weigh research initiatives on their contribution to underparticipating regions and institutions. Regional and institutional capacity are important concerns in all Federal funding, and encouraging new institutional participants and development of research centers strengthens the future capacity and diversity of the research system. Some agency programs already incorporate these criteria in *project* selection (see box 1-B).

Can Congress look to the scientific community for guidance on setting priorities? The short answer is "no." Congress wishes—perhaps now more than ever—that the scientific community could offer priorities at a macro level for Federal funding. Science Advisor Bromley and former Science Advisor Press have stated criteria and categories of

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review could thus be an iterative process. First, a pool of proposals could be identified based on scientific merit and program relevance, and those with exceptional human resources and/or research infrastructure potential so indicated. The program manager, with or without the advice of expert peers, can then pick a balanced subset from the pool. Any of several subsets might be equally meritorious—this is where selection criteria and judgment enter the process. The result is a program research portfolio that can be reshaped in succeeding years.

OTA suggests that two broad criteria could be applied to research project selection: strengthening education and human resources, and building regional and institutional capacity. How might these two additional criteria be rated in research proposals?

- ***Education and human resources* criteria would weigh proposals on their future production of new researchers or technically skilled students. Outcome measures would relate to undergraduate education, graduate training, and characteristics of new Ph.D.s—the number and quality of those entering graduate study and the research work force, respectively.**

  Contributions to human resources include increasing participation in the educational pipeline (through degree completion), the research work force, and the larger science and engineering work force. With the changing character of the student population, tapping the diversity of traditionally underrepresented groups in science and engineering (e.g., women and U.S. minorities) is vital for the long-term health of the research work force.
- ***Regional and institutional capacity* criteria would weigh proposals on their contribution to underparticipating regions and institutions. Outcome measures would include the enhanced research competitiveness of funded institutions; State, local, and private participation in the support of the research infrastructure; and an enlarged role in training and employment in targeted sectors, industries, and fields.**

  Regional and institutional capacity are important concerns in all Federal funding, reflecting the interests of taxpayers. While the major research universities are exemplary in their production of research, untapped resources could be developed in other types of educational institutions throughout the United States.[5]

Funding research to achieve all of these objectives will remain a prerogative of Congress. But decisions that add tomorrow's criteria to today's, especially in the review of project proposals at the research agencies, will expand the capability of the Federal research system.

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[5] If the Federal Government wishes to augment the economic health of a particular region, supporting research in that area is one means of achieving it. "Spin-offs" from research centers have traditionally improved local economies by encouraging development of technical industries and local research infrastructures. They also often contribute to local educational efforts and directly provide technical jobs for residents. See U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering*, OTA-TM-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

priority that they consider essential for science.[27] Each emphasizes the separation of large projects requiring new infrastructure from "small science." Press further distinguishes human resources from national crises and extraordinary scientific breakthroughs, whereas Bromley places national needs and international security concerns above all else.[28]

While the Press and Bromley formulations appear to provide frameworks for priority setting, they do not address the problem that there are few mechanisms for, and no tradition of, ranking research topics across fields and subfields of inquiry. In addition, priority setting is often resisted by the recipients of Federal funding because it orders the importance of research investments, which means that some programs do not get funded and some groups within the scientific community complain of lack of support. Consequently, Congress and the executive branch have found that the scientific community cannot make crosscutting priority decisions in science. In particular, the traditional mechanism of peer review is clearly not suited to making judgments across scientific fields. Some research communities do set priorities *within* specific research areas. However, the practice is not universal

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[27] See Frank Press, "The Dilemma of the Golden Age," *Congressional Record*, May 26, 1988, pp. E1738-E1740; and D. Allan Bromley, "Keynote Address," in Sauer, op. cit., footnote 11, p. 11. (This was augmented by "U.S. Technology Policy," issued by the Executive Office of the President, Office of Science and Technology Policy, Sept. 26, 1990).

[28] One effect of these rank-orders is the seeming creation of separate accounts, i.e., that choices could be made within each category and then across categories. Of course, such choices are being made by various participants in the research system simultaneously.

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or widespread.[29] Therefore, while recognizing the preferences of researchers, the Federal Government must set priorities at two levels: among scientifically meritorious research areas and megaprojects, and among agency programs.

Megaprojects and the Science Base

Key to the consideration of allocating public funds for science and engineering research is the simultaneous support of little and big science. Little science is the backbone of the scientific enterprise, and a diversity of research programs abounds. Not surprisingly, many investigators and their small teams shudder at the thought of organizing Federal science funding around a principle other than scientific merit—an approach that, in fact, is advocated by no one. They fear that setting priorities would change the criteria by which research funds are awarded. In particular, they seem to hear calls for priority setting as calls to direct *all* of research along specified lines, not as a means to assure that balance is achieved. For example, one goal would certainly be the maintenance of funding for a diverse science research base,[30] while other goals would include training for scientists and engineers, and supplying state-of-the-art equipment.

The Federal Government also seeks to achieve goals at many levels. These goals are likely to differ between programs that pursue specific objectives and those that seek primarily to bolster the science base. For instance, the allocation of additional monies to NIH for AIDS (acquired immunodeficiency syndrome) research, beginning in the late 1980s and continuing today, has been a clear designation of an objective as a priority research area. In addition, to enhance the science base in specific research areas, such as environmental science and high-temperature superconductivity, the Bush Administration has increased funding in certain fields. These increases, however, seem to be dwarfed by the cost of a very few, but visible, megaprojects.

Megaprojects are large, ''lumpy,'' and uncertain in outcomes and cost. Lumpy refers to the discrete nature of a project. Unlike little science projects, there can be almost no information yield from a megaproject until some large-scale investment has occurred. Presumably, a successful science megaproject provides knowledge that is important and unattainable by any other means. Because of the large expenditures and long timeframes, many science megaprojects are supported by large political constituencies extending beyond the science community.[31] Future decisions may center on ranking science megaprojects, since not all of them may be supportable without eroding funding of the science base (see figure 1-7).

There are few rules for selecting and funding science megaprojects; the process is largely ad hoc. From a national perspective, megaprojects stand alone in the Federal budget and cannot be subject to priority setting within a single agency. Nor can megaprojects be readily compared. For example, the Superconducting Super Collider (SSC) and the Human Genome Project (HGP) are not big science in the same sense. One involves construction of one large instrument, while the other is a collection of smaller projects.[32]

An issue raised about some megaprojects is their contribution to science. For instance, the Space Station has little justification on scientific grounds,[33] especially when compared with the SSC, the HGP, or the Earth Observing System, which have explicit scientific rationales. On purely scientific grounds, the benefits that will derive from investing in one project are often incommensurable with those that would be derived from investing in some other.[34]

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[29] For examples, see the National Research Council, *Renewing U.S. Mathematics: A Plan for the 1990s* (Washington, DC: National Academy Press, 1990); and the National Research Council, *The Behavioral and Social Sciences: Achievements and Opportunities* (Washington, DC: National Academy Press, 1988).

[30] This priority has been preeminent since the Federal support of research began. See House Committee on Science and Technology, op. cit., footnote 9.

[31] Phil Kuntz, ''Pie in the Sky: Big Science Is Ready for Blastoff,'' *Congressional Quarterly*, Apr. 28, 1990, pp. 1254-1260.

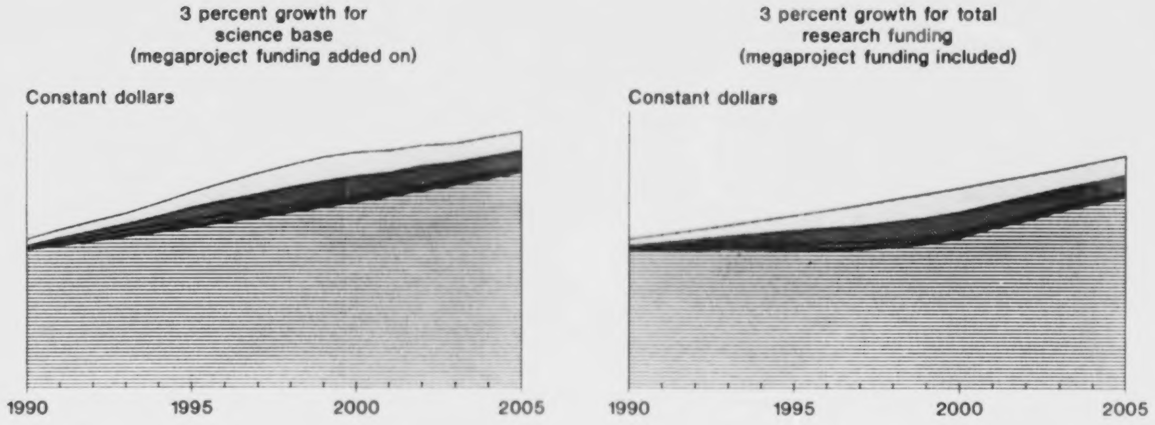
[32] The research supported by the Human Genome Project—HGP—may have some scientific benefits before the project is complete. Thus, HGP may not be big science in the strict sense of the definition outlined above. See Tom Shoop, ''Biology's Moon Shot,'' *Government Executive*, February 1991, pp. 10-11, 13, 16-17.

[33] For an early statement of this view, see U.S. Congress, Office of Technology Assessment, *Civilian Space Stations and the U.S. Future in Space*, OTA-STI-241 (Springfield, VA: National Technical Information Service, November 1984).

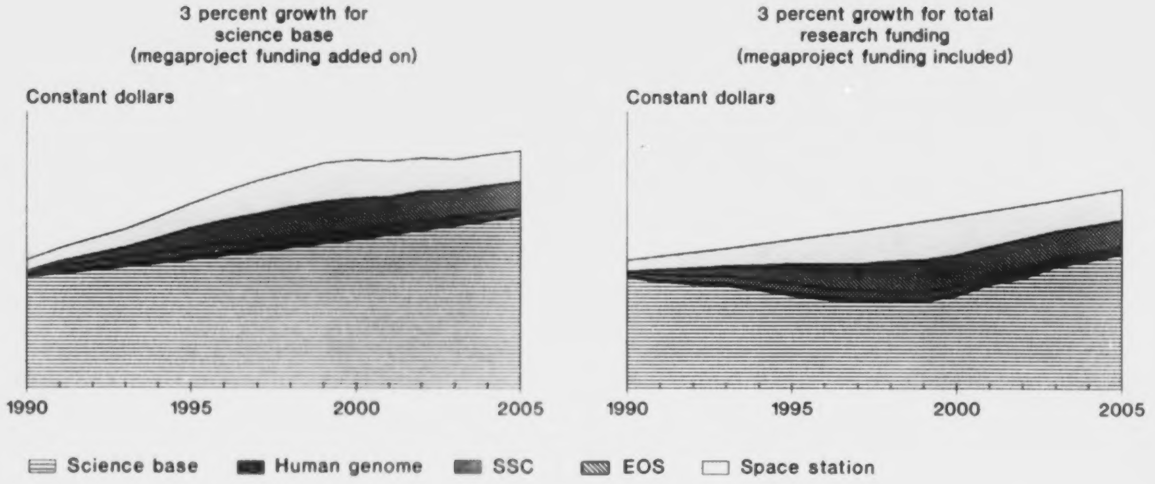
[34] This is elaborated in Harvey Averch, ''Analyzing the Costs of Federal Research,'' OTA contractor report, August 1990. Also see J.E. Sigel et al., ''Allocating Resources Among AIDS Research Strategies,'' *Policy Sciences*, vol. 23, No. 1, February 1990, pp. 1-23.

Figure 1-7—Cost Scenarios for the Science Base and Select Megaprojects: Fiscal Years 1990-2005

Current cost estimates for megaprojects



Doubled current cost estimates for megaprojects



KEY: SSC=Superconducting Super Collider; EOS=Earth Observing System.

NOTE: These figures are schematic representations of projected costs for science projects. In the figures on the left, the *science base* is projected to grow at an annual rate of 3 percent above inflation. In the figures on the right, *total Federal research funding* is projected to grow 3 percent above inflation. The cost estimates for the megaprojects are based on data from "The Outlook in Congress for 7 Major Big Science Projects," *The Chronicle of Higher Education*, Sept. 12, 1990, p. A28, and Genevieve J. Knezo, Congressional Research Service, Science Policy Research Division, "Science Megaprojects: Status and Funding, February 1991," unpublished document, Feb. 21, 1991.

SOURCE: Office of Technology Assessment, 1991.

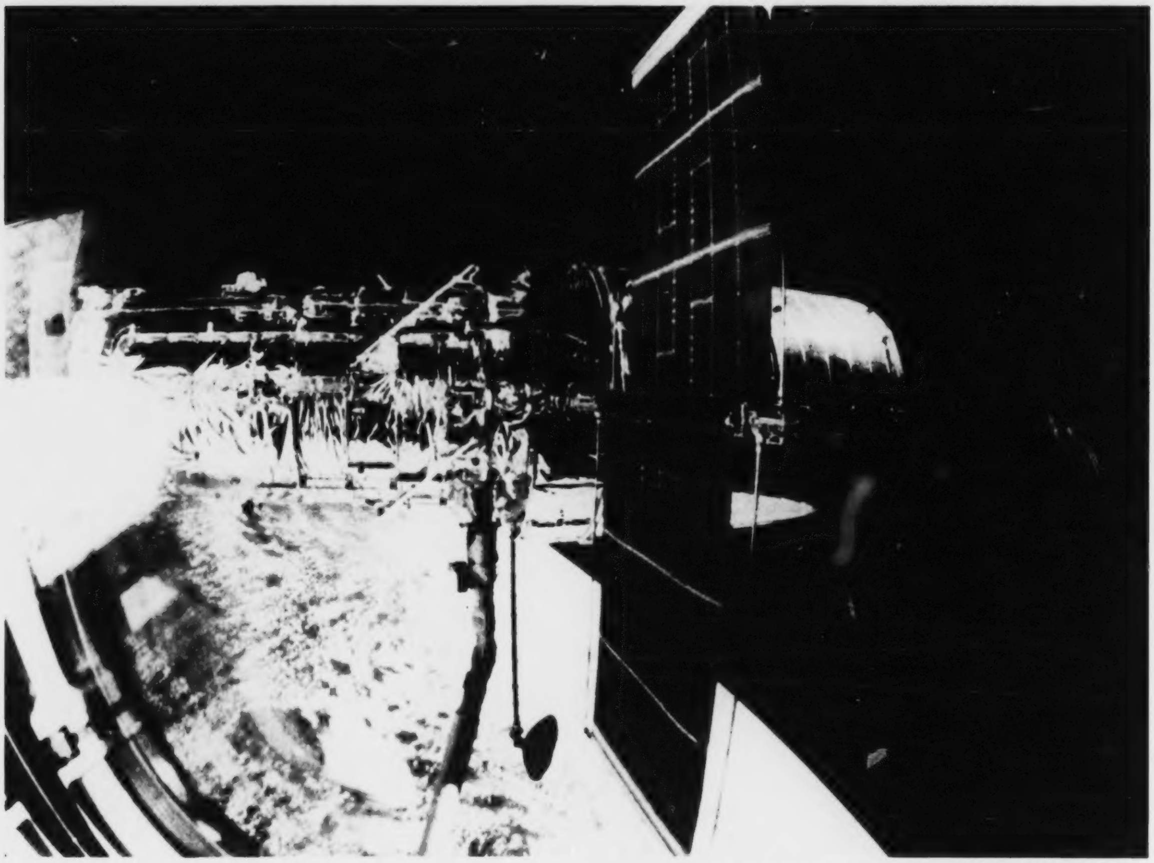


Photo credit: National Aeronautics and Space Administration

The Hubble Space Telescope (HST) is shown, still in the grasp of Space Shuttle Discovery, with only one of two solar panels extended. Earth is some 332 nautical-miles away. HST is an example of a large scientific mission at NASA.

However, because the problem of selecting among science megaprojects has most in common with the selection of complex capital projects, timeliness (why do it now rather than later?) and scientific and social merit must all be considered, as well as economic and labor benefits. At present, for example, the Space Station has considerable momentum as an economic and social project.

Other measures to evaluate and, if necessary, compare megaprojects include the number and diversity of researchers that can be supported, the scientific and technological value of information likely to be derived (i.e., the impact of the megaproject on the research community), and the ultimate utility of the new equipment and/or facility. For instance, if one project will support only a few researchers, while a second of similar cost and scientific merit will support a larger number of researchers, then perhaps the second should be favored. One might also expect preference for megaprojects that can be cost-shared internationally over those that cannot be. (Issues of costs in megaprojects are discussed below.)

Once the context for priority setting is examined, choices take on another dimension. What do U.S. society and the Federal Government expect for their research investment? What does the scientific community promise to deliver? The answers differ among participants and over time. As Robert White, President of the National Academy of Engineering, states: "It may be time that we think about whether our concern for the support of the science and technology enterprise has diverted us from attention to how we can best serve national needs.''[35]

Congressional Priority Setting

Since progress begets more opportunities for research than can be supported, setting research priorities may be imperative for shaping a successful Federal research portfolio in the 1990s.[36] To improve priority setting at a macro level, Congress should hold biennial hearings specifically on the state of the research system, including cross-field priorities in science and engineering, and the criteria used for decisionmaking within the cognizant research agencies.

For ''objective-oriented'' science and engineering that may or may not cross agencies, such as high-temperature superconductivity research, Congress should allocate resources based on plans to attain specific goals. In programs that seek primarily to fortify the science base, such as those sustained by NSF, Congress could judge progress toward goals that reflect the research capacity of the scientific community. While objective-oriented programs will contribute to these goals, the burden falls largely on science base programs to meet the goal of maintaining the research community. Congressional oversight of the research agencies could include questions of how their total research activities and specific programs, such as multiyear, capital-intensive megaprojects, contribute to expanding education and human resources, as well as to building regional and institutional capacity.

If Congress determines that more thorough and informed priority setting is required, the executive branch must disclose the criteria on which its priorities were set. OSTP is a candidate for this task. Building on the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) mechanism, which presently considers only certain cross-agency research topics, OSTP could also initiate broader priority setting. In the executive branch, Congress should insist, at a minimum, on iterative planning that results in: a) making tradeoffs among research goals; and b) applying (after scientific merit and program relevance) other criteria to research decisionmaking that reflects planning for the future. In addition, since megaproject costs affect the ability of other disciplines to start new, large projects, megaprojects are candidates for crosscutting priority setting.[37]

Structural improvements to current priority setting, especially those that facilitate the budget process and research planning within and across the agencies, would also make the tradeoffs more explicit and less ad hoc, and the process more transparent. At a minimum, agency crosscutting budgetary analysis[38] and a separate congressional cycle of priority-setting hearings (e.g., biennially) could reduce uncertainty and reveal the relationships among new and continuing projects, the support of new investigators by each agency, and the changing cost and duration estimates that currently bedevil all participants in the Federal research system.

Congress could also initiate specific changes in the executive agencies that would increase their ability to respond to changing priorities. They would include measures that encourage: 1) flexibility, so that programs can be more easily initiated, reoriented, or terminated; 2) risk-taking, so that a balanced portfolio of mainstream and ''long-shot'' research can be maintained; 3) strategic planning, so that agency initiatives can be implemented as long-term goals; 4) coordination, so that crosscutting priorities can be pursued simultaneously in many agencies; and 5) experimentation with funding allocation methods, so that new criteria can be introduced into project selection and evaluated to ascertain the value added to decisionmaking.

It is symbolic that across the Federal research system, national policymakers, sponsors, and performers alike have acknowledged that the funding process would benefit from careful consideration of research priorities, especially at the macro level.[39] Whether their exhortations lead to clearer research agendas (including the suspension or postponement of some activities) remains to be seen, and whether these investments are balanced, well-managed, and yield the desired consequences is hard to judge in real time. But surely the policy process is enriched by drawing a map of the choices, the benefits, and the costs to be incurred by the scientific community and the Nation.

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[35] Robert M. White, ''Science, Engineering, and the Sorcerer's Apprentice,'' Presidential Address to the National Academy of Engineering, Washington, DC, Oct. 2, 1990, p. 12.

[36] Brooks writes, ''Today many of the same negative signals that existed in 1971 are again evident. Will science recover to experience a new era of prosperity as it did beginning in the late seventies, or has the day of reckoning that so many predicted finally arrived?'' Harvey Brooks, ''Can Science Survive in the Modern Age? A Revisit After Twenty Years,'' *National Forum*, vol. 71, No. 4, fall 1990, p. 33.

[37] For example, see Alissa Rubin, ''Science Budget: Hill Must Make Hard Choices Among Big-Money Projects,'' *Congressional Quarterly Weekly Report*, vol. 49, Feb. 9, 1991, p. 363.

[38] This was a principal recommendation proposed in National Academy of Sciences, op. cit., footnote 6.

ISSUE 2: Understanding Research Expenditures

Summary

Many in the scientific community claim that the "costs of doing research" are rising quickly, especially that the costs of equipment and facilities outpace increases in Federal research funding. The most reliable data are available from research agencies, and can be analyzed at two levels: 1) total Federal expenditures for research, and 2) individual components of research project budgets. OTA finds that Federal expenditures for research have risen faster than inflation, and more researchers are supported by the Federal Government than ever before. Salaries and indirect costs account for the largest and fastest growing share of these expenditures. However, these findings do not truly address the claims expressed above, because of the numerous and sometimes inconsistent meanings of the costs of doing research.

Most research activities become cheaper to complete with time, as long as the scope of the problem and the standards of measurement do not change. However, advances in technology and knowledge are "enabling": they allow deeper probing of more complex scientific problems. Experiments are also carried out in an environment driven by competition. While competition is part of the dynamic of a healthy research system, competition drives up demand for funding, because success in the research environment often correlates highly with the financial resources of research groups.

Direct cost containment by the research agencies may not be an appropriate Federal role, although Congress might direct the agencies to pursue specific measures at their discretion and to evaluate their effectiveness. Instead, greater cost-accountability could be encouraged by the executive branch and Congress. In particular, the Federal Government should seek to eliminate the confusion around allowable indirect costs, and develop better estimates of future expenditures, especially for megaprojects where costs often escalate rapidly.

Discussion

Many researchers state as an overriding problem that the "costs of doing research" have risen much faster than inflation in the Gross National Product (GNP), and Federal expenditures for research have not kept pace with these rising costs. Included in the costs of research are salaries, benefits, equipment, facilities, indirect costs, and other components of research budgets. Equipment and facilities are typically named as most responsible for increased costs.[40]

However, addressing these claims is difficult, because it is hard to define what is meant by the costs of doing research. Research activities become cheaper to complete with time, as long as the scope of the problem and the standards of measurement do not change. But this is not the way progress is made. Advances in technology and knowledge are "enabling": they allow deeper probing of more complex problems. This is an intrinsic challenge of research.

There is an extrinsic challenge as well. Experiments are carried out in an environment that is driven by competition. Competition is part of the dynamic of a healthy research system. One sign of a

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[39] In addition to those cited previously, see Robert M. Rosenzweig, President, Association of American Universities, "Address to the President's Opening Session, The Gerontological Society of America," 43rd annual meeting, Boston, MA, Nov. 16, 1990; John H. Dutton and Lawson Crowe, "Setting Priorities Among Scientific Initiatives," *American Scientist*, vol. 76, No. 6, November-December 1988, pp. 599-603; Albert H. Teich, "Scientists and Public Officials Must Pursue Collaboration To Set Research Priorities," *The Scientist*, vol. 4, No. 3, Feb. 5, 1990, pp. 17; and Tina M. Kaarsberg and Robert L. Park, "Scientists Must Face the Unpleasant Task of Setting Priorities," *The Chronicle of Higher Education*, vol. 37, No. 23, Feb. 20, 1991, p. A52.

[40] See Janice Long, "Bush's Science Advisor Discusses Declining Value of R&D Dollars," *Chemical & Engineering News*, vol. 68, No. 17, Apr. 23, 1990, pp. 16-17; *Science: The End of the Frontier?*, op. cit., footnote 14; and OTA interviews at the University of Michigan and Stanford University, July-August 1990.

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healthy research system is that it can expand to produce more research. "Needs" in the research environment are thus open-ended.

Although competition exists in the research community, it does not necessarily drive down costs, as would be expected in typical "markets." In an earlier era, the chief cost of research was the annual salary of the principal investigator (PI). Today, the PI is often the head of a team with many players and access to the latest research technologies. In the face of inherent uncertainty about the eventual outcomes of research,[41] sponsors must apply various criteria in predicting the likelihood of eventual project success, such as access to sophisticated equipment or the availability of appropriately trained personnel. These criteria are often associated with higher rather than lower costs. Success, therefore, often comes to those who spend the most (especially if research teams are relatively evenly matched). In fact, competitive proposals are often the most expensive and low bids can actually *decrease* a proposer's chance of winning a grant. Because additional personnel and sophisticated equipment are seen by sponsors as being instrumental in the conduct of research, costs are ultimately limited by what sponsors are willing to spend.

Products, or "outputs," of scientific research have also traditionally defied measurement.[42] Consequently, the price of research measured in economic terms—the cost per-unit output—is extremely difficult to estimate. Analysis using crude measures of scientific "productivity" suggests that the cost of producing a published paper or performing a given scientific measurement has *decreased*: with less than double the investment per year since 1965, more than double the number of papers are published today in academia, and more than double the number of Ph.D. scientists are employed in the academic sector.[43] By these measures, science has grown more productive (and consequently the cost per-unit output of research has decreased).[44] However, there is no metric to compare a "unit" of today's research with one in the past.

Thus, "Are the costs of research going up?" is not a useful question for policy purposes. Research expenditures by the Federal Government are awarded and accounted for on an annual basis. What gets included in these expenditures can be modified by adjusting the scale and pace of scientific research. Especially for basic research, these factors are variable, though the competition for personal and institutional recognition pushes PIs toward larger teams and more sophisticated instrumentation. In mission-oriented science, the rate of research may be dictated by pressing concerns (e.g., curbing the AIDS epidemic is desired as quickly as possible).

For policy purposes, research costs equal expenditures: if the Federal Government provides more funds, "costs" will go up accordingly. A more useful policy question might be: "Is Federal spending on individual components of research project budgets reasonable?" The Federal Government will tend to have a different point of view on this question from the research performer. OTA has explored both perspectives.

Incomplete and murky data on research expenditures complicate questions on the costs of research. Analysis of Federal expenditures for the conduct of research must factor what Federal agencies are willing to spend for personnel, facilities, and instrumentation, while analysis of expenditures by research performers is confounded by the expenditure accounting schemes that vary from research institu-

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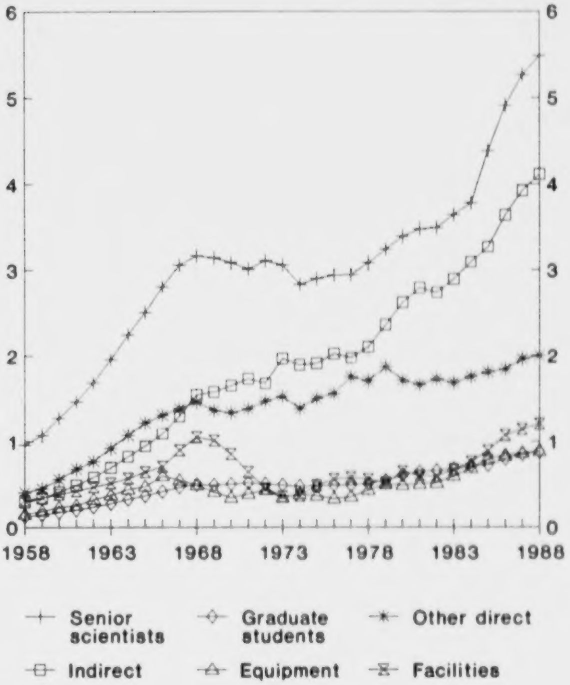
[41] See, for example, Richard Nelson, "The Allocation of Research and Development Resources: Some Problems of Public Policy," *Economics of Research and Development*, Richard Tybout (ed.) (Columbus, OH: Ohio State University Press, 1965), pp. 288-308. Nelson points out that ". . . research and development has economic value because the information permits people to do things better, and sometimes to do things that they did not know how to do before. . . [but] there is no simple way to evaluate the benefits society can expect from the knowledge created by different kinds of R&D. . . ." (pp. 293-294). Also see Mansfield, op. cit., footnote 3.

[42] Published papers and patents have been used as proxies, but they cannot be standardized. See Susan E. Cozzens, "Literature-Based Data in Research Evaluation: A Manager's Guide to Bibliometrics," final report to the National Science Foundation, Sept. 18, 1989.

[43] On the former, see H.D. White and K.W. McCain, "Bibliometrics," *Annual Review of Information Science and Technology*, vol. 24, 1989, pp. 119-186; and on the latter, National Science Board, op. cit., footnote 12, tables 5-17 and 5-30.

[44] However, even if one acccepts these definitions of research output, the productivity of research relative to other economic activities might still be stagnant. Economist William Baumol explains that research, due to the price of labor rather than increases in its productivity, has an ". . . inherent tendency to rise in cost and price, persistently and cumulatively, relative to the costs and prices of the economy's other outputs." He warns that ". . . the consequence may be an impediment to adequate funding of R&D activity, that is, to a level of funding consistent with the requirements of economic efficiency and the general economic welfare." See W.J. Baumol et al., *Productivity and American Leadership: The Long View* (Cambridge, MA: MIT Press, 1989), ch. 6, quotes from pp. 116, 124.

Figure 1-8—Estimated Cost Components of U.S. Academic R&D Budgets: 1958-88 (in billions of 1988 dollars)



SOURCE: Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues*, (Washington, DC: National Academy Press, 1989), figure 2-43.

NOTE: Constant dollars were calculated using the GNP Implicit Price Deflator.

DEFINITION OF TERMS: Estimated personnel costs for *senior scientists* and *graduate students* include salaries and fringe benefits, such as insurance and retirement contributions. *Other direct* costs include such budget items as materials and supplies, travel, subcontractors, computer services, publications, consultants, and participant support costs. *Indirect* costs include general administration, department administration, building operation and maintenance, depreciation and use, sponsored-research projects administration, libraries, and student-services administration. *Equipment* costs include: 1) reported expenditures of separately budgeted current funds for the purchase of research equipment, and 2) estimated capital expenditures for fixed or built-in research equipment. *Facilities* costs include estimated capital expenditures for research facilities, including facilities constructed to house scientific apparatus.

DATA: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division of Science Resource Studies, "Survey of Scientific and Engineering Expenditures at Universities and Colleges"; National Institutes of Health; American Association of University Professors; National Association of State Universities and Land Grant Colleges.

tion to research institution.[45] In addition, much of the current debate over rising expenditures takes place within a context of agency budget constraints and pressures felt by research performers.

The most reliable data on Federal research expenditures are available from research agencies, and can be analyzed at two levels: 1) total Federal expenditures for research, and 2) individual components of research project budgets. OTA finds that total expenditures on individual components of grants have risen over inflation, but not nearly at the rate for total Federal expenditures for research (see figure 1-8). Instead, growth in the *size* of the research work force supported by the Federal Government seems to account for the largest increase in Federal research expenditures. Also, the largest component increases of research project budgets are for salaries and indirect costs.

Trends in Components of Total Federal Research Expenditures

Analyzing Federal expenditures for specific line items of research budgets reveals interesting trends (again see figure 1-8). First, reimbursements for indirect costs are the fastest growing portion of Federal research expenditures. Indirect costs is a term that stands for expenses that research institutions can claim from the Federal Government for costs that cannot be directly attributed to a single research project, i.e., they are distributed over many investigators who share research infrastructure and administrative support. Federal support for indirect costs has increased since the 1960s, with the largest increases in the late 1960s and the 1980s. In 1958, indirect cost billings comprised 10 to 15 percent of Federal academic R&D funding. By 1988, that share had risen to roughly 25 percent.[46] In addition, some agencies allow more than other agencies in indirect costs. For example, in 1988, the indirect cost as a percent of the total R&D expenditures allowed at

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[45] For an attempt to compare expenditures at two public and two private universities associated with the performance of National Science Foundation-funded research, see G.W. Baughman, "Impact of Inflation on Research Expenditures of Selected Academic Disciplines 1967-1983," report to the National Science Foundation and the National Center for Educational Statistics, NSF/PLN 8017815, Nov. 8, 1985. Also see Daniel E. Koshland, "The Underside of Overhead," *Science*, vol. 249, May 11, 1990, p. 3; and "The Overhead Question," letters in response to Koshland's editorial, *Science*, vol. 249, July 6, 1990, pp. 10-13.

[46] National Science Foundation, *The State of Academic Science and Engineering* (Washington, DC: 1990), p. 121.

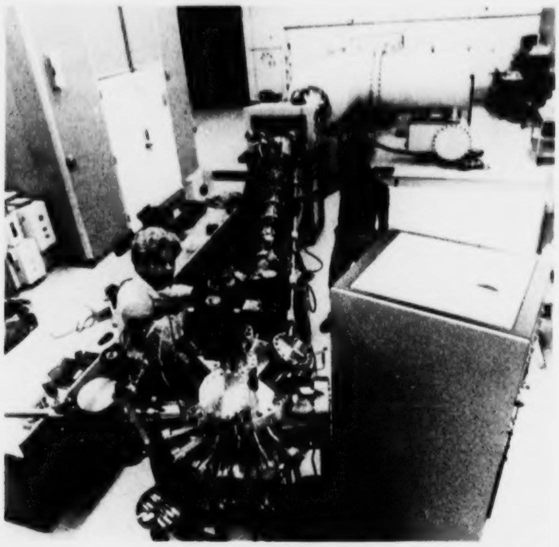

Photo credit: Bob Kalmbach, University of Michigan

These scientists are in an ion beam laboratory at the University of Michigan. Research often requires state-of-the-art equipment.

NIH was 30 percent, whereas it was less than 24 percent for NSF (a proportion unchanged since the mid-1980s).[47]

Second, increasing numbers of investigators and rising salaries (and the benefits that go with them) have driven up the price of the personnel component of direct costs. University personnel speak of the increased competition for faculty with other sectors of the economy, and note that faculty salaries have been rising significantly over inflation during the last decade. The average total compensation (salaries and benefits) for academic Ph.D.s in the natural sciences and engineering increased from $59,000 (1988 dollars) in 1981 to more than $70,000 in 1988. In the same period, the number of full-time equivalent scientists and engineers employed in academic settings rose steadily from about 275,000 to almost 340,000.[48]

Third, Federal support for *academic* research equipment alone increased from $0.5 billion in 1968 (1988 dollars) to $0.9 billion in 1988. Despite pronounced increases and improvements in equipment stocks in the 1980s, 36 percent of department heads still describe their equipment as inadequate (to conduct state-of-the-art research). This is in part due to the reduction in the obsolescence time of equipment and instrumentation use since the late 1970s.[49]

Finally, the Federal share of all capital expenditures for *academic* facilities (which include both research and teaching facilities) has never topped one-third. Now it is less than 10 percent.[50] For university *research* facilities alone, the Federal Government provided an estimated 11 and 16 percent, respectively, of private and public university capital expenditures in 1988-89. The government also supports research facilities through depreciation, operation, and maintenance charges accounted for in the indirect cost rate. In 1988, the Federal Government supplied nearly $1 billion to support university infrastructure. Almost 20 percent was for facilities depreciation, while the rest was recovered for operation and maintenance costs.[51]

Academic administrators claim that with growing frequency, aging laboratories and classroom buildings falter and break down,[52] and many claim that facility reinvestment has not kept pace with growing needs. However, the picture is not clear. For example, when asked by NSF, a majority of the research administrators and deans at the top 50 research universities replied that their facilities were "good to excellent," whereas a majority of the research administrators and deans in the schools below the top 50 estimated that their facilities were "fair to poor."[53]

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[47] Ibid., p. 142; and Association of American Universities, *Indirect Costs Associated With Federal Support of Research on University Campuses: Some Suggestions for Change* (Washington, DC: December 1988).

[48] Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington, DC: National Academy Press, October 1989), pp. 2-34 and 2-47, based on National Science Foundation data.

[49] National Science Foundation, *Academic Research Equipment in Selected Science/Engineering Fields: 1982-83 to 1985-86*, SRS 88-D1 (Washington, DC: June 1988).

[50] For public universities, 50 to 60 percent of the facilities funds come from the States, and 30 percent from bond issues. For private universities, roughly one-third comes from the Federal Government, while another one-third is from donations. See Michael Davey, *Bricks and Mortar: A Summary and Analysis of Proposals to Meet Research Facilities Needs on College Campuses* (Washington, DC: Congressional Research Service, 1987).

[51] Over the period 1982 to 1988, the Federal support of university infrastructure grew by over 70 percent in real terms. These figures are presented in ''Enhancing Research and Expanding the Human Frontier,'' op. cit., footnote 26, pp. 61-62. The document further states that: ''Each academic institution must provide a certification that its research facilities are adequate (to perform the research proposed) as a condition of accepting research grants.'' The ''. . . $12 billion of needed, but unfunded capital projects. . . .'' reported in the National Science Foundation surveys of universities ''. . . has not had an apparent effect on the ability of universities to accept Federal research funds.''

[52] Karen Grassmuck, ''Colleges Scramble for Money to Reduce Huge Maintenance Backlog, Estimated to Exceed $70 Billion; New Federal Help Seen Unlikely,'' *The Chronicle of Higher Education*, vol. 37, No. 6, Oct. 10, 1990, pp. A1, A34.

The crux of the facilities problem is that research and academic centers can always use new or renovated buildings, but how much is enough? Even though "need" may not be quantified in the different sectors of the research enterprise, a demand certainly exists. For example, when NSF solicited proposals for a $20 million program in 1989 to address facilities needs, it received over 400 proposals totaling $300 million in requests.[54]

Federal Policy Responses to Increased Demand

Many Federal agencies have experimented with grant-reducing measures, such as the salary caps required by Congress and temporarily imposed by NSF and NIH, the ceilings on indirect costs currently in place at USDA, the elimination of cost-blind reviews of proposals in some research programs at NIH, the limitation of funds supplied in new grants to researchers with multiple Federal grants at the National Institute of General Medical Sciences, and the institution of fixed-price grants in some NSF programs.[55] Congress could pursue permanent grant-reducing measures to slow or limit increases in research expenditures on individual research grants. However, it may not be an appropriate Federal role to dictate specific allowable costs in research projects. In general, allowing market forces to determine costs has been a tradition in Federal policy.

Instead, greater cost-accountability could be encouraged. One benefit of cost-accountability could be incentives for performers to spend less than what was targeted in project budgets, and greater flexibility in expenditures for performers (e.g., researchers could be encouraged to use the money saved one year in the next year, a so-called no-cost extension). Within such cost-accountability measures, Congress might also direct the agencies to experiment with cost-containment schemes and to evaluate their effectiveness.

Greater cost-acountability is especially important in the calculation of indirect cost rates. At present, the guidelines for calculating costs are detailed in conjunction with OMB Circular A-21 and have been in force since 1979. Every major research university has an indirect rate established for the current fiscal year for recovery of costs associated with sponsored research. These rates have evolved over many years as a result of direct interaction and negotiation with the cognizant Federal agency. There is a wide range of indirect costs rates among universities, with most noticeable differences between public and private institutions (rates tend to be higher at private institutions). Rates vary because of: 1) significant differences in facilities-related expenditures, 2) underrecovery by some universities, 3) imposition of limits by some government agencies in the negotiation process, and 4) diversity in assigning component expenditures as direct or indirect.[56]

However, confusion around what is contained in the indirect cost rate is getting worse, not better. This reflects, in part, the difficulty of separating expenditures along lines of research, instruction, and other functions.[57] Recent investigations by the Office of Naval Research and the House Committee on Energy and Commerce have also uncovered significant variation in the accounting of indirect costs by the cognizant Federal agencies and research universities.[58] These differences should be sorted out, and more explicit and understandable guidelines devised.

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[53] National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1988*, NSF 88-320 (Washington, DC: September 1988), p. 26.

[54] See Jeffrey Mervis, "Institutions Respond in Large Numbers to Tiny Facilities Program at NIH, NSF," *The Scientist*, vol. 4, No. 8, Apr. 16, 1990, p. 2.

[55] For a discussion of various options, see Barbara J. Culliton, "NIH Readies Plan for Cost Containment," *Science*, vol. 250, Nov. 30, 1990, pp. 1198-1199; and Colleen Cordes, "Universities Fear That U.S. Will Limit Payments for Overhead Costs Incurred by Researchers," *The Chronicle of Higher Education*, vol. 37, No. 3, Nov. 21, 1990, pp. A19, A21.

[56] Association of American Universities, op. cit., footnote 47.

[57] Eleanor C. Thomas and Leonard L. Lederman, National Science Foundation, Directorate for Scientific, Technological, and International Affairs, "Indirect Costs of Federally Funded Academic Research," unpublished paper, Aug. 3, 1984, p. 1.

[58] See Marcia Barinaga, "Stanford Sails Into a Storm," *Science*, vol. 250, Dec. 21, 1990, p. 1651; "Government Inquiry," *Stanford Observer*, November-December 1990, pp. 1, 13; Colleen Cordes, "Conceding 'Shortcomings,' Stanford To Forgo $500,000 in Overhead on U.S. Contracts," *The Chronicle of Higher Education*, Jan. 30, 1991, vol. 37, No. 20, pp. A19, A22; and Colleen Cordes, "Stanford U. Embroiled in Angry Controversy on Overhead Charges," *The Chronical of Higher Education*, Feb. 6, 1991, vol. 37, No. 21, pp. A1, A20-A21.

It is also important to stress accuracy in developing estimates of costs for megaprojects. When the Federal Government "buys" a megaproject, the initial investment seems to represent a point of no return. Once the go, no-go decision has been made at the national level, the commitment is expected to be honored. However, criteria for consideration in the funding of a science megaproject could conceivably include: startup and maintenance costs, cost of unanticipated delay, cost of users' experiments, and likely changes in the overall cost of the project from initial estimate to completion. Some estimates for science megaprojects double before the construction is even begun, and costs of operating a big science facility once it is completed are sometimes not considered.[59]

Megaprojects will always be selected through a political process because of their scale, lumpiness, and incommensurability. Since their costs, especially in following years, affect other disciplines' abilities to start new, large projects, megaprojects could well be considered as candidates for crosscutting, priority-setting analysis *before* the practical point of no return. As the National Academy of Sciences' report on budget priorities reminds: ". . . it is necessary to specify the institutions, individuals, and organizations that will be served; [and] the costs . . . of the program."[60] The cost of investment for the Federal Government is an important criterion to apply to all scientific research, including megaprojects.

Performer Expectations

Not all problems in research costs can be addressed by the Federal Government. Many researchers point to higher expectations, which require more spending, and competition in the university environment. In the academic environment, researchers are asked today to publish more papers, shepherd more graduate students, and bring in more Federal funding than their predecessors.[61] If they do not meet these expectations, some report a sense of failure.[62] This is true even if they have succeeded, but not by as much or as quickly as they had hoped.

To boost research productivity and to compete with other research teams, faculty attempt to leverage their time with the help of postdoctoral fellows, nontenure track researchers, and graduate students who are paid lesser salaries. Due to the shortage of faculty positions for the numbers of graduate students produced, young Ph.D.s have been willing to take these positions in order to remain active researchers. This availability of "cheap labor" is seen by many senior researchers and their institutions as the only way they can make ends meet in competing for grants.[63] This is a trend toward an "industrial model," where project teams are larger and responsibilities are more distinct within the group.[64] While the expenditures charged to an *individual* grant may be less (since more grants may be required to support the diverse work of the group), the overall cost of supporting a PI and the larger group are greater.[65]

Some experiments have been attempted on U.S. campuses to temper the drive for more research publications (as a measure of productivity). For example, at Harvard Medical School, faculty are allowed to list only five publications for consideration in tenure reviews, with similar numbers set for other promotions.[66] Thus, the quality and importance of the candidate's selected set of papers is stressed, though measuring these characteristics remains controversial.[67] However, strong incentives militate against reducing research volume. Most overhead is brought into the university by a small number of research professors. (At Stanford, 5 percent of the faculty bring in over one-half of the indirect cost dollars.) Any measure that would reduce grant awards and publications produced by these investigators would deprive the university of revenues. In fact, many universities in tight financial straits try to *maximize* the level of research volume.[68]

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[59] For example, see Kuntz, op. cit., footnote 31; and David P. Hamilton, "The SSC Takes on a Life of Its Own," *Science*, vol. 249, Aug. 17, 1990, pp. 371-372.

[60] National Academy of Sciences, op. cit., footnote 6, p. 11.

[61] This is especially true in entrepreneurial research areas such as biotechnology. See Henry Etzkowitz, "Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science," *Minerva*, vol. 21, summer-autumn 1983, pp. 198-233.

[62] *Science: The End of the Frontier?* op. cit., footnote 14.

[63] Labor economist Alan Fechter, Executive Director, Office of Scientific and Engineering Personnel, National Research Council, writes: ". . . personnel costs constitute roughly 45 percent of total costs and . . . this percentage has remained reasonably stable over time. Given that salaries of faculty (i.e., principal investigators) have been rising during the 1980s, this suggests that the staffing pattern of research projects has been changing, with the input of PIs decreasing relative to . . . other, less expensive resources. There is some evidence to support this hypothesis in the report of GUIRR [Government-University-Industry Research Roundtable] . . . [that] finds in academia an increasing ratio of nonfaculty to faculty," personal communication, Nov. 15, 1990. See Government-University-Industry Research Roundtable, op. cit., footnote 48.

[64] Elsewhere this has been called the "industrialization" of science, or ". . . a new *collectivized* form in which characteristics of both the academic and industrialized modes are intermingled." See John Ziman, *An Introduction to Science Studies* (Cambridge, England: Cambridge University Press, 1984), p. 132 (elaborated below).

[65] Noted at OTA Workshop on the Costs of Research and Federal Decisionmaking, July 19, 1990.

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The Federal Government must seek to understand better the trends in expenditures in the research environment—especially variations across institutional settings—and craft government policies to allocate resources effectively. Reliable analyses of research expenditures at all of the Federal agencies are not available. Future studies of expenditures should look not only at the economic forces that increase (and decrease) research expenditures, but also at the sociology of research organizations, including the demography of research teams and institutional policies for sponsored projects.[69]

Federal agencies clearly must understand increasing demands to fund research, as research universities and laboratories are an invaluable resource for the United States. Devising mechanisms for coping with research expenditures is one of the central challenges to the Federal system for funding research in the 1990s.

ISSUE 3: Adapting Education and Human Resources To Meet Changing Needs

Summary

Three issues are central to education and human resources for the research work force:

1. Recent projections of shortages of Ph.D. researchers in the mid-1990s have spurred urgent calls to augment Ph.D. production in the United States. OTA believes that the likelihood of these projections being realized is overstated, and that these projections alone are poor grounds on which to base public policy. For instance, they assume continued growth in demand in both academic and industrial sectors, independent of the level of Federal funding. In both this and previous OTA work, however, OTA has indicated the value to the Nation—regardless of employment opportunities in the research sector—of expanding the number and diversity of students in the educational pipeline (K-12 and undergraduate) for science and engineering, preparing graduate students for career paths in or outside of research, and, if necessary, providing retraining grants for researchers to move more easily between research fields.

2. Total participation in science and engineering can be increased if the opportunities and motivation of presently underparticipating groups (e.g., women, minorities, and researchers in some geographic locations) are addressed. Federal legislation has historically played an important role in recruiting and retaining these groups. Also, "set-aside" programs (which offer competitive research grants to targeted groups) and mainstream disciplinary programs are tools that can enlarge, sustain, and manage the diversity of people and institutions in the research system.

3. Research in many fields of science and engineering is moving toward a larger, more "industrial" model, with specialized responsibilities and the sharing of infrastructure. In response, the Federal Government may wish to acknowledge changes in the composition of research groups and to enhance the opportunities and rewards for postdoctorates, nontenure track researchers, and others.

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[66] The National Science Foundation also now limits the number of publications it will consider, as evidence of an applicant's track record, in reviewing grant proposals. See David P. Hamilton, "Publishing By—and For?—the Numbers," *Science*, vol. 250, Dec. 7, 1990, pp. 1331-1332.

[67] See N.L. Geller et al., "Lifetime Citation Rates to Compare Scientists' Work," *Social Science Research*, vol. 7, No. 4, 1978, pp. 345-365; and A.L. Porter et al., "Citations and Scientific Progress: Comparing Bibliometric Measures With Scientist Judgments," *Scientometrics*, vol. 13, 1988, pp. 103-124.

[68] OTA interviews at Stanford University, Aug. 2-3, 1990.

[69] See Susan E. Cozzens et al. (eds.), *The Research System in Transition*, Proceedings of a NATO Advanced Study Institute, Il Ciocco, Italy, Oct. 1-13, 1989 (Dordrecht, Holland: Kluwer, 1990).

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Discussion

The graduate science and engineering (s/e) education system in the United States, especially at the doctoral level, is the envy of the world. Foreign nationals continue to seek graduate degrees from U.S. institutions at an ever-growing rate.[70] From 1977 to 1988, the number of Ph.D.s awarded in s/e by U.S. universities increased by nearly 50 percent[71] (for a breakdown by field and decade, see figure 1-9). This exemplary production of Ph.D.s continues a noble tradition abetted by Federal research and education legislation.

With passage of the National Defense Education Act of 1958 (Public Law 85-864) in the wake of the Sputnik launch, the Federal Government became a pivotal supporter of pre- and postdoctoral science, engineering, and indeed, non-s/e students.[72] Additional programs were soon established by NSF, NASA, NIH, and other Federal agencies. This period of growth in Federal programs offering *fellowships* (portable grants awarded directly to students for graduate study) and *traineeships* (grants awarded to institutions to build training capacity) was followed by decreases in the 1970s.[73] In s/e, this decline was offset by the rise in the number of *research assistantships* (RAs) for students awarded on Federal research grants to their mentors.

During the 1980s, RAs became the principal mechanism of graduate s/e student support, increasing at 5 percent per annum since 1980, except in agricultural sciences where RAs have actually declined. (A comparison of the types of graduate student Federal support, 1969 and 1988, is presented in figure 1-10.)[74] This trend is consistent with the growing "research intensiveness" of the Nation's universities: more faculty report research as their primary or secondary work activity, an estimated total in 1987 of 155,000 in academic settings.[75]

Thus, the Federal Government has historically played both a direct and indirect role in the production and employment of s/e Ph.D.s. Both as the primary supporter of graduate student stipends and tuition, and as a patron, mainly through research grants, the Federal Government has effectively intervened in the doctorate labor market and helped shape the research work force.

Supplying the Research Work Force

The U.S. graduate research and education system trains new researchers and skilled personnel for all sectors of the Nation's work force (and arguably for some countries abroad). Since 1980, NSF estimates that the *total* s/e work force (all degrees) has grown at 7.8 percent per year, which is four times the annual rate of growth in total employment. Scientists and engineers represented 2.4 percent of the U.S. work force in 1976 and 4.1 percent in 1988.[76]

While new s/e Ph.D.s have traditionally been prepared for faculty positions in academia—almost 80 percent were employed in this sector in 1987[77]—in broad fields such as engineering and disciplines such as computer science the demand for technical labor outside of academia is great. Other fields, like chemistry, benefit from having a large set of potential academic and industrial employment opportunities. This diversity makes any labor market

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[70] See National Science Board, op. cit., footnote 12, p. 55; and National Research Council, *Foreign and Foreign-Born Engineers in the United States* (Washington, DC: National Academy Press, 1988). Although OTA uses the shorthand "scientists and engineers," it recognizes the range of fields represented by the term. They are encompassed by the degree-granting categories in the National Science Foundation's Science Resources Studies reports: engineering, physical sciences, environmental sciences, mathematical sciences, computer/information sciences, life (biological/agricultural) sciences, psychology, and social sciences.

[71] National Science Foundation, *Science and Engineering Doctorates: 1960-89, NSF 90-320* (Washington, DC: 1990), table 1.

[72] For details, see U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force*, OTA-TM-SET-35 (Washington, DC: U.S. Government Printing Office, December 1985), pp. 44-49.

[73] Association of American Universities, *The Ph.D. Shortage: The Federal Role* (Washington, DC: Jan. 11, 1990), pp. 15-16.

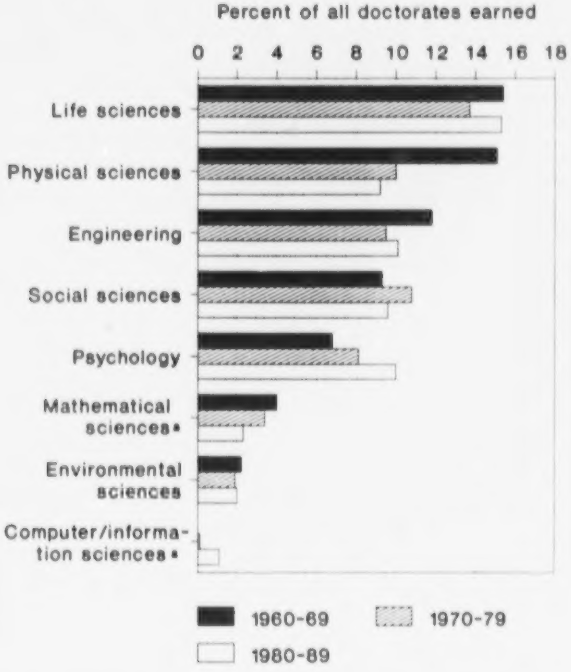
[74] If plotted by gender, this figure would look quite different. Traditionally, women have not received as many fellowships and traineeships as men or foreign students on temporary visas, are more dependent on personal or family resources during graduate study, and suffer higher attrition before completing the Ph.D. See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 79-80; and National Science Foundation, *Women and Minorities in Science and Engineering*, NSF 90-301 (Washington, DC: January 1990), pp. 23-24.

[75] National Science Board, op. cit., footnote 12, pp. 46, 57. These 155,000 represented 37 percent of the doctorate scientists and engineers employed in the United States in 1987.

[76] Ibid., p. 67. Among Ph.D.s, the ratio of employed scientists to engineers is 5 to 1.

[77] Ibid., app. table 5-19.

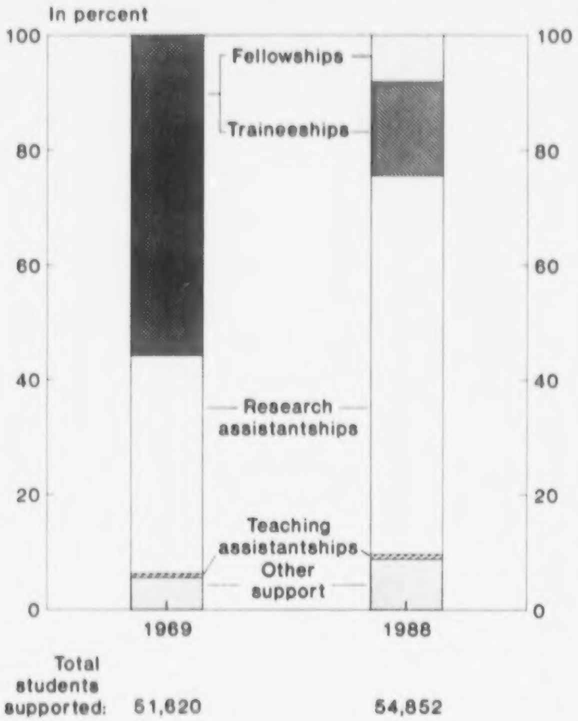
Figure 1-9—Percentage Distribution of Doctorates by Science and Engineering Field: 1960-89 (by decade)



ª Degrees in computer science were not awarded until the late-1970s; before then, computer science was counted with mathematical sciences.

SOURCE: National Science Foundation, *Science and Engineering Doctorates: 1960-89*, NSF 90-320 (Washington, DC: 1990), detailed statistical tables, table 1.

Figure 1-10—Federal Support of Science and Engineering Graduate Students, 1969 and 1988 (by type of support)



NOTE: Fellowships and traineeships were not reported separately in 1969.

SOURCE: National Science Board, *Science and Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), appendix table 2-18; and National Science Foundation, *Graduate Student Support and Manpower Resources in Graduate Science Education, Fall 1969*, NSF 70-40 (Washington DC: 1970), table C-11a.

fluid and its forecasting difficult, but the major components can be analyzed.[78]

Based on changing demographics and historical trends in baccalaureate degrees, some studies have projected that the scientific community will face a severe shortage in its Ph.D. research work force during the 1990s.[79] However, there are pitfalls in the methodologies employed in these projections of Ph.D. employment demand.[80] Predicting the demand for academic researchers must also account for enrollment and immigration trends, anticipated career shifts and retirements, and the intentions of new entrants, as well as shifting Federal priorities and available research funding. All of these are subject to change, and may vary by institution, field, and region of the country.[81] In addition, OTA questions the ability of statistical analyses to predict future demand for s/e Ph.D.s, especially as responses to market signals and other societal influences are known to adjust both interest and opportunities. Even without the prospect of a slackening economy in the 1990s, such projections would be unreliable. Given the track record of these forecasting tools, they are poor grounds alone on which to base public policy.[82]

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[78] For examples, see Eileen L. Collins, "Meeting the Scientific and Technical Staffing Requirements of the American Economy," *Science and Public Policy*, vol. 15, No. 5, October 1988, pp. 335-342; and National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988).

[79] See Richard C. Atkinson, "Supply and Demand for Scientists and Engineers: A National Crisis in the Making," *Science*, vol. 246, Apr. 27, 1990, pp. 425-432.

[80] Indeed, shortages may not be the biggest concern. Changes in demographic composition and quality of graduates may be more problematic. For a discussion, see Howard P. Tuckman, "Supply, Human Capital, and the Average Quality Level of the Science and Engineering Labor Force," *Economics of Education Review*, vol. 7, No. 4, 1988, pp. 405-421.

[81] For example, see Ted I.K. Youn, "Studies of Academic Markets and Careers: An Historical Review," *Academic Labor Markets and Careers*, D.W. Breneman and Ted I.K. Youn (eds.) (Philadelphia, PA: The Falmer Press, 1988), pp. 8-27.

Noting the uncertainty of projections, OTA finds that concentration on the preparedness of the pipeline to produce Ph.D.s (i.e., increasing the number of undergraduates earning baccalaureates in s/e) by introducing flexibility into the system is the most robust policy. If shortages begin to occur in a particular field, not only should graduate students be encouraged to complete their degrees (i.e., reducing attrition), but prepared undergraduates should be induced, through various proven Federal support mechanisms, to pursue a Ph.D.[83] Those scientists who would have otherwise left the field might stay longer, those who had already left might return, and graduate students in nearby fields could migrate to the field experiencing a shortage. If shortages do not materialize, then the Nation's work force would be enhanced by the availability of additional highly skilled workers.

OTA believes there are initiatives that maintain the readiness of the educational pipeline to respond to changing demands for researchers and that enhance the diversity of career opportunities—sectors and roles—for graduates with s/e Ph.D.s.[84] Congress could urge NSF and the other research agencies to intensify their efforts to maintain a robust educational pipeline for scientific researchers (and to let the labor market adjust Ph.D. employment). Funding could be provided for undergraduate recruitment and retention programs, for grants to induce dedicated faculty to teach undergraduates, and for the provision of faculty retraining grants.[85]

Expanding Diversity and Research Capacity

Trends in the award of s/e degrees attest to 20 years of steady growth in human resources (see figure 1-11). These data are a sustained record of scientific education at the Ph.D. level. However, the benefits of this education do not accrue equally to all groups, and therefore to the Nation. Women and U.S. racial and ethnic minorities, despite gains in Ph.D. awards through the 1970s and 1980s, lag the participation of white males. Relative to their numbers in both the general and the undergraduate populations, women and minorities (and the physically disabled) are underparticipating in the research work force.[86] Meanwhile, foreign nationals on temporary visas are a growing proportion of s/e Ph.D. recipients (and about one-half are estimated to remain in the United States).[87]

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[82] OTA reached this conclusion after examining the performance of various models of academic and industrial labor markets. See Office of Technology Assessment, op. cit., footnote 72, especially chs. 3 and 4. Recent independent confirmation of this conclusion appears in Alan Fechter, "Engineering Shortages and Shortfalls: Myths and Realities," *The Bridge*, fall 1990, vol. 20, pp. 16-20.

[83] See Office of Technology Assessment, op. cit., footnote 74.

[84] See two reports: U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988); and *Higher Education for Science and Engineering*, OTA-TM-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

[85] The National Science Foundation, as prescribed in their enabling legislation, is equally responsible for science education and the support of the Nation's basic research. It has gradually expanded its programs, long focused on the graduate end of the pipeline, to address issues in undergraduate and K-12 education. For example, see National Science Foundation, *Research on Key Issues in Science and Engineering Education: Targeted Program Solicitation*, NSF 90-149 (Washington, DC: 1990). Perhaps faculty retraining programs, both to highlight changes in educational strategies and developments in research, should be considered. Retraining has been acknowledged as important for maintaining the engineering work force, and retraining grants have been provided in some programs within the Department of Defense and other agencies. Additional research retraining grants could certainly be financed by the research agencies and perhaps administered through the Federal laboratories. Retraining for teaching would fall primarily to universities that wish to improve the classroom (i.e., undergraduate) teaching of its faculty. See National Research Council, op. cit., footnote 78; and Neal Lane, "Educational Challenges and Opportunities," *Human Resources in Science and Technology: Improving U.S. Competitiveness*, Proceedings of a Policy Symposium for Government, Academia, and Industry, Mar. 15-16, 1990, Washington, DC, Betty Vetter and Eleanor Babco (eds.) (Washington, DC: Commission on Professional in Science and Technology, July 1990), pp. 92-99.

[86] Degrees alone tell an incomplete story of future supply of scientists and engineers. For example, college attendance rates of 18- to 21-year-olds vary by gender and race. Since 1972, 35 to 40 percent of whites of both sexes in the cohort have attended college with Black rates in the 25 to 30 percent range. By 1988, female attendance exceeded that of males and was rising, whereas male attendance of both races peaked in 1986-87 and declined thereafter. See National Science Board, op. cit., footnote 12, p. 50, figure 2-2.

[87] For an overview, see Commission on Professionals in Science and Technology, *Measuring National Needs for Scientists to the Year 2000*, Report of a Workshop, Nov. 30-Dec. 1, 1988 (Washington, DC: July 1989), pp. 20-24. For more on graduate engineering education, see Elinor Barber et al., *Choosing Futures: U.S. and Foreign Student Views of Graduate Engineering Education* (New York, NY: Institute of International Education, 1990).

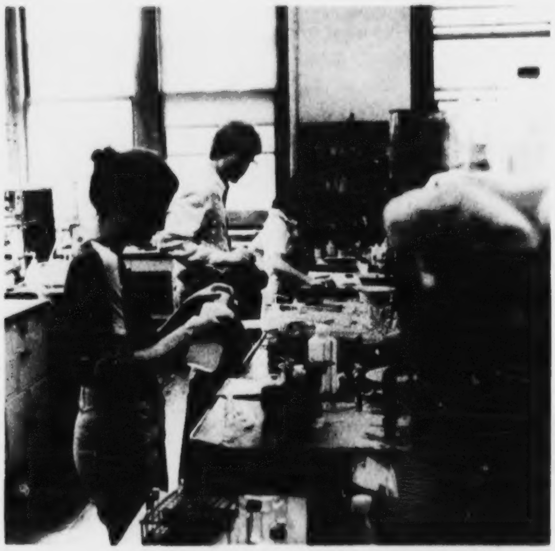
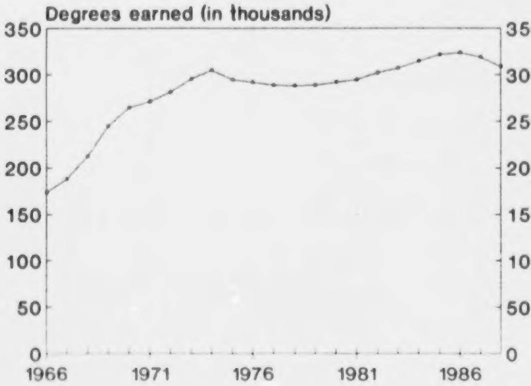


Photo credit: Bob Kalmbach, University of Michigan

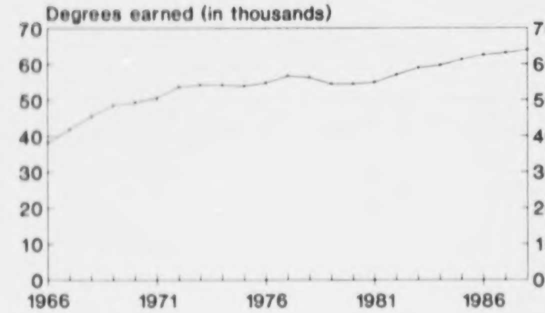
These students are in a laboratory at the University of Michigan. Laboratory classes are a crucial part of undergraduate education in the physical sciences.

Figure 1-11—Science and Engineering Degrees: 1966-88 (by level)

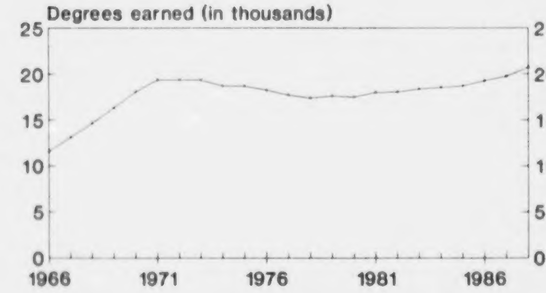
Bachelors



Masters



Doctorates



SOURCE: National Science Foundation, *Science and Engineering Degrees: 1966-88, A Source Book*, NSF 90-312 (Washington, DC: 1990), detailed statistical tables, table 1.

Increasing the participation at all educational levels in s/e by traditionally underrepresented groups is a challenge to the human resources goals of the Federal research system. Enhancing the participation of targeted groups at the Ph.D. level will be particularly difficult, as the research work force adjusts to changing fiscal conditions and funding of research. As OTA found in an earlier study, "... equal opportunity for participation in higher education and in research for all groups is a long-term social goal that will be achieved only with steady national commitment and investments."[88] Congress could amend the Higher Education Act (reauthorization is scheduled for the 102d Congress) and the Science and Engineering Equal Opportunities Act to add provisions that address diversity in research and science education funding, and emphasize undergraduate teaching opportunities at certain categories of institutions such as historically Black colleges and universities (HBCUs).[89] Programs targeted to U.S. minorities, women, and the physically disabled could help to expand the pool of potential scientists and engineers. It is clear that in this particular realm of human resources, market forces alone will not increase the participation of these groups. Policy intervention is required and Congress is empowered to intervene.

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[88] Office of Technology Assessment, op. cit., footnote 74, p. 101.

[89] For the scope of current provisions, see Margot A. Schenet, Congressional Research Service, "Higher Education: Reauthorization of the Higher Education Act," Issue Brief, May 15, 1990; and Public Law 96-516, 94 Stat. 3010, Section II, Science and Engineering Equal Opportunities Act, Part B, as amended by Public Law 99-159, 1982.

The capacity of the research system could also be augmented by encouraging "have-not" institutions to concentrate excellence in select research programs (departments and centers) and build from there. Attempting to enter the top ranks of federally funded research-intensive universities through across-the-board enhancement of all research programs may lead to each program being unable to garner enough support to improve research capability. Various programs that address geographical diversity, such as the NSF Experimental Program to Stimulate Competitive Research (EPSCoR), or greater consideration of geography in funding allocation within the portfolios of mainstream scientific merit-based programs, could build research capacity that benefits States and regions as well as the Nation as a whole.

Research and Education in Flux

Calls for the reform of higher education in the 21st century are now emanating from many presidents of research universities.[90] These calls center on improved undergraduate education and a better balance between research and teaching. Many see a need to change the reward system of the university, since asking universities to augment the teaching of undergraduates may be misplaced if faculty continue to view this as a drain on time that would be better spent doing research.[91]

The tension between research and teaching is perpetuated by the provision of funds meant to improve both the institution's research performance and teaching capability. A common perception during the 1960s was that Federal dollars that supported research also benefited undergraduate teaching because these top researchers would communicate their excitement about developments "at the laboratory bench" to undergraduate and graduate students alike. In the 1980s, with the separation between research and undergraduate education becoming more pronounced, the connection between research progress and the cultivation of human resources grew more tenuous.[92] These calls for increased undergraduate teaching by faculty seek to alter an academic research and teaching model in the United States that is already under strain.

The predominant mode of academic research in the natural sciences and engineering begins with a research group that includes a PI (most often a faculty member), a number of graduate students, one or several postdoctoral scientists, technicians, and perhaps an additional nonfaculty Ph.D. researcher. While this group may be working on a single problem funded by one or two grants, subsets of the group may work on different but related problems funded simultaneously by multiple project grants. (In the social sciences, the groups tend to be smaller, often numbering only the faculty member and one to two graduate students.)

In addition, the dominant model to launch a career as a young scientist is movement from one research university to another with an assistant professorship, the attainment of a first Federal research grant, and the re-creation of the mentor's professional lifestyle (e.g., independent laboratory, graduate students, postdoctorates). For an institution to subscribe to this model tends to shift much of the actual responsibility for awarding tenure from the department faculty to the Federal Government. While university officials say there is ". . . no fixed time in which researchers are expected to become self-sufficient through outside grants . . . researchers who have failed to win such grants are less likely to

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[90] Prominent among them are the two institutions that OTA studied as part of this assessment, Stanford and Michigan. See Karen Grassmuck, "Some Research Universities Contemplate Sweeping Changes, Ranging From Management and Tenure to Teaching Methods," *The Chronicle of Higher Education*, vol. 37, No. 2, Sept. 12, 1990, pp. A1, A29-31.

[91] This would include nothing less than a redefinition of faculty scholarship that includes teaching. See Ernest L. Boyer, *Scholarship Reconsidered: Priorities of the Professoriate* (Princeton, NJ: The Carnegie Foundation for the Advancement of Teaching, 1990). Also see Alliance for Undergraduate Education, *The Freshman Year in Science and Engineering: Old Problems, New Perspectives for Research Universities* (University Park, PA: 1990).

[92] See Anthony B. Maddox and Renee P. Smith-Maddox, "Developing Graduate School Awareness for Engineering and Science: A Model," *Journal of Negro Education*, vol. 59, No. 3, 1990, pp. 479-490. This connection was also highlighted when institutions of higher education receiving Federal assistance were required to provide certain information on graduation rates, reported by program and field of study. See Public Law 101-542, Title I—Student Right-To-Know, Stat. 2381-2384, Nov. 8, 1990, p. 104.

Photo credit: Jay Mangum Photography

Seventh graders observe research in a "cleanroom." Seeing science at work is important for all age groups.

earn tenure than their colleagues who have found such support.''[93]

There is doubtless a role for universities to play in the diversification of research careers of recent Ph.D.s. New Ph.D.s find it difficult to entertain alternative opportunities if they have no experience with them. Thus, programs that offer a summer in a corporate laboratory or part of an academic year at a 4-year liberal arts college can help advanced graduate students visualize working in settings other than the university. Arrangements that link an HBCU or liberal arts college to a research university or national laboratory stretch the resources and experience of both participating institutions.[94]

New Models: University and Federal

Other models of education could be encouraged that feature a greater sharing of resources (e.g., equipment and space) and people (e.g., doctoral students, nonfaculty researchers, and technicians). Models that stress research in units other than academic departments, research in *nonacademic* sectors, and *nonresearch* roles in academia could be entertained. Some Federal research agencies already recognize the development of this form of teamwork in their funding programs and support of the research infrastructure. For example, these models are institutionalized in the centers programs sponsored by NSF. Centers, which support individual researchers (as faculty and mentors) as well, may represent a new way of doing business for NSF. Centers are also featured at NIH intra- and extramurally; at the laboratories affiliated with DOD, DOE, and NASA; and at the agricultural experiments stations funded through block grants by USDA.[95]

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[93] See Debra E. Blum, ''Younger Scientists Feel Big Pressure in Battle for Grants,'' *The Chronicle of Higher Education*, vol. 37, No. 4, Sept. 26, 1990, p. A16. As one researcher puts it: ''Leading universities should make their own decisions about who their faculty are going to be, and not leave it to the study sections of NIH.'' Quoted in David Wheeler, ''Biomedical Researchers Seek New Sources of Aid for Young Scientists,'' *The Chronicle of Higher Education*, vol. 36, No. 42, July 5, 1990, p. A23.

[94] To date, such arrangements have been most common in undergraduate engineering. One coalition, spearheaded by a 5-year $15 million National Science Foundation grant, will establish a communications network for information dissemination, faculty exchange, workshops, and outreach to elementary, secondary, and community college students. The participating universities are City College of New York, Howard, Maryland, Massachusetts Institute of Technology, Morgan State, Pennsylvania State, and Washington. See ''NSF Announces Multi-Million Dollar Grants to Form Engineering Education Coalitions,'' *NSF News*, Oct. 9, 1990.

Research in general is becoming increasingly interdisciplinary, i.e., it requires the meshing of different specializations to advance a research area.[96] Academic departments house specialists by discipline whose research will be performed in units—centers, institutes, programs—that cut across the traditional departmental organization on campus. Such organized research units have a history on U.S. university campuses, but not as dominant structures.[97] However, as outlined above, in many fields there is movement toward an industrial model of research, characterized by larger research teams and a PI who spends more time gathering funds to support junior researchers who in turn devote their full time to research. For many of today's research activities, this model seems to enhance productivity and allow more complex research problems to be tackled, by specializing responsibilities within the research team and sharing infrastructure.[98]

The expanding size and complexity of research teams under the responsibility of entrepreneurial PIs and "lab chiefs" fosters financial and organizational strains. To help ease the strains caused by a transition in some parts of the research community to an industrial model, the Federal research agencies could encourage alternative models of education-in-research that feature a greater sharing of resources and people. While it is not the role of the Federal Government to dictate university research or education policies, it can provide the impetus for examining and experimenting with those policies through grant support.

Mainstream agency programs have always awarded research funds to advance the state of knowledge in their programmatic areas mainly on the core criterion of "scientific merit." Though difficult to define precisely, this is generally taken as a necessary condition for funding. Recognition that discipline-based agency programs favor investigator track record in proposal review, but that other factors reflect important objectives of research funding, led to the creation of set-aside programs. These programs, originating both in Congress and within agencies, restrict the competition for scarce funds according to some characteristic of the investigator or the proposal. Set-aside programs thus evaluate proposals first and foremost on scientific merit, but redefine the playing field by reducing the number of competitors. (Examples discussed in the full report include NIH's Minority Biomedical Research Support Program; NSF's aforementioned EPSCoR, Presidential Young Investigator, and Small Grants for Experimental Research programs; and the Small Business Innovation Research programs conducted by various Federal agencies.)

Taken together, such programs address the competitive disadvantage faced by young, minority, or small business research performers; by researchers and institutions in certain regions of the Nation; and by ideas deemed "high-risk" by expert peers or that do not fit with traditional disciplinary emphases. The proliferation of such programs over the last 20 years has been a response to the desire to enlarge both the participation in, and the capacity of, the Federal research system. But because the annual funding for each program remains modest (typically in the $10 million range), program impact is limited.

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[95] In 1990, the National Science Foundation supported 19 Engineering Research Centers and 11 Science and Technology Research Centers (STCs) at $48 million and $27 million, respectively. Thus, together they account for less than 10 percent of the National Science Foundation's budget, while providing a long-term funding base (5 to 11 years) for interdisciplinary and high-risk projects oriented to the applied, development, and commercial-use end of the research continuum. See Joseph Palca and Eliot Marshall, "Bloch Leaves NSF in Mainstream," *Science*, vol. 249, Aug. 24, 1990, p. 850. In the block-grant, multi-investigator approach embodied by STCs: "NSF has rolled the dice on an experiment in science, and it will take some time to know whether it has come up with a winner." See Joseph Palca, "NSF Centers Rise Above the Storm," *Science*, vol. 251, Jan. 4, 1991, pp. 19-22, quote from p. 22.

[96] For example, see A.L. Porter and D.E. Chubin, "An Indicator of Cross-Disciplinary Research," *Scientometrics*, vol. 8, 1985, pp. 161-176; and Don E. Kash, "Crossing the Boundaries of Disciplines," *Engineering Education*, vol. 78, No. 10, November 1988, pp. 93-98.

[97] D.I. Phillips and B.P.S. Shen (eds.), *Research in the Age of the Steady-State University* (Boulder, CO: Westview Press, 1982). Three models of organized research units (which are common in industry and the Federal laboratories) have taken root on campus—agricultural experiment stations, water resources research centers, and engineering research centers. See Robert S. Friedman and Renee C. Friedman, "Science American Style: Three Cases in Academe," *Policy Studies Journal*, vol. 17, fall 1988, pp. 43-61.

[98] See Ziman, op. cit., footnote 64, pp. 132-139. In other words, the traditional academic model of faculty-mentor plus graduate student is today accompanied by production units that demand more teamwork and sharing—what has long been common, for example, in astronomy, fusion, and high-energy physics research.

Without set-asides, the Federal Government would have little confidence that once scientific merit has been demonstrated, other differentiating criteria would be applied to the funding of researchers. However, to a research system already strapped for resources, the funding of such "tangential" concerns is seen by some as diverting precious dollars away from the core need to advance knowledge.[99]

Human resources are perhaps the most important component of the research system. Through support of scientists and engineers, graduate students, and the educational pipeline, the Federal Government is instrumental in the creation of a strong research work force, which has been expanding under this support since the 1950s. In the 1990s, however, the research work force—in its myriad forms of organization and scale of effort—has reached such a size that it feels strain under the Federal Government's present approach to supporting the conduct of research. In addition, accommodating to an expanding research work force, and to the changing ethnic and racial composition of students in the educational pipeline for science and engineering, poses challenges to the Federal research system. Human resources issues have implications not only for the number of participants in the research work force, but also for the character of the research that new entrants automatically bring to the Nation's research enterprise.

ISSUE 4: Refining Data Collection and Analysis To Improve Research Decisionmaking

Summary

Data collected on the health of the Federal research system—dollars spent for research, enrollments, and academic degrees awarded in specific fields, and outcome measures such as publications and citations—are extensive. In other areas, however, data are scarce. For instance, almost no consistent information exists on the size and composition of the *research* work force (as opposed to the total science and engineering work force), or what proportion is supported by Federal funds (across agencies).

Most research agencies, with the exception of NSF and NIH, devote few resources to internal data collection. Consequently, most analyses must rely on NSF and NIH data and indicators alone, potentially generalizing results and trends that might not apply to other agencies. Furthermore, it is not clear how agency data are used to inform research decisionmaking, as some challenge current policy assumptions and others are reported at inappropriate levels of aggregation.

OTA suggests additional information that could be collected for different levels of decisionmaking, concentrating in areas of policy relevance for Congress and the executive branch. However, better information may not be cost-free. The idea is not merely to *add* to data collection and analysis, but to substitute for current activities not used for internal agency decisionmaking or external accountability. Refined inhouse and extramural data collection, analysis, and interpretation would be instructive for decisionmaking and managing research performance in the 1990s.

Discussion

Many organizations collect and analyze data on the research system. First and foremost is NSF, with its numerous surveys, reports, and electronic data systems that are publicly available. Certainly the most visible compendium of data on the research system is the biennial report, *Science & Engineering Indicators* (SEI), issued since 1973 by the National Science Board, the governing body of NSF.[100] Other sources include the other Federal research agencies; the National Research Council; the Congressional Research Service; professional societies, especially the American Association for the Advancement of

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[99] Change comes incrementally and at the margins of the enterprise. But if one were constructing the system from scratch, mainstreaming criteria to reflect the multiple objectives of research funding would be a key element to consider.

[100] See Susan E. Cozzens, "Science Indicators: Description or Prescription?" OTA contractor report, September 1990. Note that *Science & Engineering Indicators* (SEI) was named *Science Indicators* until 1987. SEI builds on data collected, published, and issued in many other reports by the Science Resources Studies Division of the National Science Foundation.

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Science; and other public and special interest groups.[101]

Together these databases and analyses provide a wealth of information: time series on the funding of research and development (R&D); expenditures by R&D performer (e.g., universities and colleges, industry, Federal laboratories), by source of funding, and by type (basic, applied, or development); numbers of students who enroll in and graduate with degrees in s/e; characteristics of precollege science and mathematics programs and students in the education pipeline; and size, sectors of employment, and activities of the s/e (especially Ph.D.) work force.[102] Detailed analyses of the Federal budget by research agency are available each year, and impacts on specific disciplines and industries can often be found.

These publications provide a basis for understanding the Federal research system. But even with each of these organizations devoting significant resources to the collection of information, better data are needed to guide possible improvements in the system.[103] With its establishment, NSF was legislatively authorized as the Federal agency data liaison and monitor for science and technology.[104] Data can be used to monitor, evaluate, anticipate, and generally inform decisionmakers—both within agencies and within Congress. Although many data are already collected, they are rarely matched to policy questions. Other (or more) data could improve decisionmaking.

Information for Research Decisionmaking

OTA defines four categories of data that could be useful in decisionmaking: 1) research monies—how they are allocated and spent; 2) personnel— characteristics of the research work force; 3) the research process—how researchers spend their time and their needs (e.g., equipment and communication) for research performance; and 4) outcomes—the results of research. Besides the considerable gaps and uncertainties in measures of these components, the most detailed analyses are done almost exclusively at NSF and NIH, and not at the other major research agencies.[105] These analyses may not generalize across the Federal research system. Comparable data from all of the agencies would be very useful to gain a more well-rounded view of federally supported research.

Perhaps the most fundamental pieces of information on the research system are the size, composition, and distribution of the *research* work force, and how much is federally funded. Varying definitions pose problems for data collection and interpretation (for an example, see box 1-C). These data are important to understand the health and capacity of the research system and its Federal components. In addition, there is evidence that research teams are changing in size and composition. This trend is also important to measure since it affects the form and distribution of Federal funding.

Second, information is needed on expenditures (e.g., salaries, equipment, and indirect costs) in research budgets; for all research performers—academia, Federal laboratories, and industry; and by subfield of science and engineering. Data on how Federal agencies allocate monies within project budgets could also be compiled, and would illuminate how funding decisions are made within the research agency and would help to clarify funding levels in specific categories of expenditures. Better cost accounting and forecasting for megaprojects is

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[101] For example, see National Research Council, *Surveying the Nation's Scientists and Engineers: A Data System for the 1990s* (Washington, DC: National Academy Press, 1990). Under multiagency support, the National Research Council is well known for collecting, analyzing, and disseminating information on Ph.D. recipients. For a statement of its crosscutting role, see National Academy of Sciences, *The National Research Council: A Unique Institution* (Washington, DC: National Academy Press, 1990). For a summary of major databases on science and engineering (individuals and institutions), see National Research Council, *Engineering Personnel Data Needs for the 1990s* (Washington, DC: National Academy Press, 1988), app. A-2.

[102] For example, the Government-University-Industry Research Roundtable of the National Academy of Sciences, with data compiled by the National Science Foundation's Policy Research and Analysis Division, provided much useful analysis on the state of academic R&D and changes since the early 1960s. Government-Industry-University Research Roundtable, op. cit., footnote 48.

[103] These efforts must also be seen in the context of the massive Federal data system. The components most relevant to research are the data series compiled and reported by the Census Bureau, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and the National Center for Education Statistics.

[104] For the scope of these data collection and analysis responsibilities, see England, op. cit., footnote 8, app. 1.

[105] For example, the National Institutes of Health sets aside 1 percent of its research budget for research evaluation and internal analysis of the investigators and programs it supports. The Department of Energy, the National Aeronautics and Space Administration, the Office of Naval Research, and the National Science Foundation have all conducted ad hoc inhouse evaluations of the research they support and the efficiency of the operations needed to select and manage various research portfolios.

Box 1-C—How Many "Scientists" Are There?

How one defines a "scientist," "engineer," researcher," or "postdoctorate" is in the eye of the beholder. Depending on what data collection method is used, counting scientists and engineers (S/E's) can result in radically different estimates.[1]

Definition	*Number*
S/E's in the U.S. work force (defined by job held)	5,300,000
S/E's in academia (defined by responses to surveys in academic institutions)	712,000
S/E Ph.D.s in *basic* research—all sectors (defined by responses to surveys of Ph.D.s)	187,000
S/E Ph.D.s in academia, where research is either their *primary* or *secondary* work activity (defined by responses to surveys of Ph.D.s)	155,000
S/E Ph.D.s in *basic* research in academia (defined by reponses to surveys of Ph.D.s)	66,000
Full-time equivalent S/E investigators in Ph.D. institutions (e.g., two researchers who each spend half-time on research would be counted as one full-time equivalent S/E investigator)	63,000

None of these definitions is the "right" one. Rather, the appropriate definition depends on the purpose for which the number is to be used. Throughout this report, OTA refers to scientists and engineers in many ways: e.g., by participation in the U.S. work force, by sector of employment, by work activity, by field, by highest degree earned. The reader should keep in mind that the numbers can change by tenfold or more depending on who is counted as a scientist or engineer.

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[1] Most of the following numbers are taken from the National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: 1989), and are 1987 or 1988 estimates by the National Science Foundation's Science Resources Studies Division. The number of full-time equivalent investigators is based on analysis by the National Science Foundation's Policy Research and Analysis Division, as reported in Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington, DC: National Academy Press, October 1989), p. 2-51.

surely needed. Continuous upward revisions of cost estimates for megaprojects disrupt decisions about their future funding priority.

Third, data on the research process could be improved in amount and kind. One trend (mentioned above) that OTA has noted, mostly with anecdotal evidence and inferences from analyses of expenditures, is the increasing size of research groups, both within the university structure and through Federal support of centers. This trend has policy implications for the cost of research, its interdisciplinary capabilities, the changing demographics of the work force, and the aspirations of young researchers. It also reflects how researchers may spend their time. More data on "production units" in research, and their dependence on Federal funding relative to other sources, would augment enrollment, Ph.D. award, and work activity data. Changes in the structure of production units have also influenced the research process and the volume—and perhaps the character—of outcomes.[106] Information on the research process would yield a firmer foundation on which to base funding allocation decisions, specifically: 1) how researchers spend their time, 2) movement of research teams toward a more industrial model in the allocation of responsibilities, 3) changing equipment needs and communications technologies, and 4) requirements and average time to attain promotions in the scientific work force.

Evaluating Research Outcomes

Because of the fundamental and elusive nature of research, measuring its outcomes—in knowledge and education—is very difficult. The most elusive outcome is cultural enrichment—the discovery and growth of scientific knowledge. As OMB Director Richard Darman has said (speaking of the proposed Moon/Mars mission): "No one can put a price on uplifting the Nation." Research has resulted in many benefits and is funded precisely for this reason. This kind of benefit is nearly impossible to measure. However, there are some proxies.

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[106] The role of laboratory chief or team leader combines entrepreneurial and administrative/supervisory tasks. Both are essential to the funding and longevity of the productive research unit. On the emergence of the entrepreneurial role on campus, see Etzkowitz, op. cit., footnote 61.

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When looking at research as a contribution to education, numbers of degrees can be tallied and assertions made about skills added to the Nation's work force. When looking at research as creating new knowledge, one tangible "output" is papers published by scientific investigators to communicate new information to their scientific peers. Communicating the results of scientific research to colleagues through publication in the open literature is considered to be an important feature of good research practice.[107] Perhaps the best approach is to construct workable indicators and include a rigorous treatment of their uncertainties.

One tool that has been vigorously developed for measuring the outcomes of research is bibliometrics—the statistical analysis of scientific publications and their attributes.[108] Intrinsic to scientific publication is the referencing of earlier published work on which the current work is presumably based or has utilized in some way. References are a common feature of the scientific literature, and by counting how often publications are cited, bibliometrics can arrive at a weighted measure of publication impact—not only whether publications have been produced, but also what impact those publications have had on the work of other scientists.[109]

OTA has explored several examples of new data sets that could be compiled using bibliometrics.[110] First, universities can be ranked according to an output or citation measure—the citation rates for papers authored by faculty and others associated with each institution.[111] Institutions can be ranked by total number of cited papers, the total citations received by all papers associated with each institution, and the ratio of number of citations to the number of publications, namely, the *average citations per cited paper*. This appears to be a more discerning measure than either publication or citation counts alone.

For example, a ranking of institutions by average citation rates can be used in conjunction with the list of top universities, in Federal R&D funding received, to link inputs with outputs. Together, these measures illuminate differences in rank.[112] Not only can publishing entities be analyzed, but so can fields of study. For instance, "hot fields," in which the rate of publication and citation increases quickly over a short period of time, can be identified and "related fields," in which published papers often cite each other, can be mapped.[113] Because of problems of interpretation in bibliometric analysis, it should be seen as "value-added" to research decisionmaking, not as stand-alone information. Bibliometrics could be used to help monitor outcomes of research, e.g., publication output and other information from the research system.[114]

Criteria that go beyond bibliometric data could be specified for such evaluations. These criteria could include the originality of research results, the project's efficiency and cost, impacts on education and the research infrastructure, and overall scientific merit. Such research project evaluation could be

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[107] For example, see Leah A. Lievrouw, "Four Research Programs in Scientific Communication," *Knowledge in Society*, vol. 1, summer 1988, pp. 6-22; and David L. Hull, *Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science* (Chicago, IL: University of Chicago Press, 1988).

[108] Researchers in western Europe have been particularly active during the 1980s. For example, see B.R. Martin and J. Irvine, *Research Foresight* (London, England: Pinter, 1989); and A.F.J. van Raan (ed.), *Handbook of Quantitative Studies of Science and Technology* (Amsterdam, Holland: North-Holland, 1988).

[109] Interpreting citation patterns remains a subject of contention. For caveats, see D.O. Edge, "Quantitative Measures of Communication in Science: A Critical Review," *History of Science*, vol. 17, 1979, pp. 102-134. The definitive overview is contained in Eugene Garfield, *Citation Indexing: Its Theory and Application in Science, Technology and Humanities* (New York, NY: John Wiley & Sons, 1979).

[110] See Henry Small and David Pendlebury, "Federal Support of Leading Edge Research: Report on a Method for Identifying Innovative Areas of Scientific Research and Their Extent of Federal Support," OTA contractor report, February 1989; and Henry Small, "Bibliometrics of Basic Research," OTA contractor report, September 1990.

[111] The analysis below is based on Institute for Scientific Information databases and Small, op. cit., footnote 110.

[112] As part of the agenda for future exploration, institutions receiving primarily directed funds or block grants (e.g., in agriculture) could be compared with those that are investigator-initiated. This comparison would help to test the claim that targeted appropriations (e.g., earmarking) lead to the production of inferior research. For discussion, see ch. 5 of the full OTA report.

[113] For example, see Angela Martello, "Governments Led in Funding 1989-90 'Hot Papers' Research," *The Scientist*, vol. 4, No. 16, Aug. 20, 1990, pp. 20-23.

[114] See U.S. Congress, Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Returns?* OTA-TM-SET-36 (Washington, DC: U.S. Government Printing Office, April 1986); and Ciba Foundation, *The Evaluation of Scientific Research* (New York, NY: John Wiley & Sons, 1989). For evidence on U.S. research performance relative to seven other industrialized countries, see "No Slippage Yet Seen in Strength of U.S. Science," *Science Watch*, vol. 2, No. 1, January/February 1991, pp. 1-2.

Photo credit: Jay Mangum Photography

A Research Triangle Park scientist accesses a computer network. Computers can greatly enhance data collection and presentation.

employed to augment agency decisions on funding and administration of research programs. (Some research agencies already utilize certain aspects of research program evaluation.[115])

Utilizing Data for Research Decisionmaking

In a policy context, information must be presented to those who are in positions to effect change by allocating or redirecting resources. In the diverse structure of the Federal research system, research decisions are made at many levels. For example, an agency program manager requires data specific to the purview of his/her program, while OMB and OSTP must be aware of trends in science that span broad fields, institutions, and agencies, as well as those that apply only to specific fields, performers, and research sponsors.

Drawing on NSF expertise as the possible coordinating agency, information could be collected at each agency on proposal submissions and awards, research expenditures by line items in the budget, and the size and distribution of the research work force that is supported (including the funding that this work force receives from other sources). Information must be available to decisionmakers for evaluation as well as to illuminate significant trends. Often data can be presented in the form of *indicators*, e.g., comparisons between variables, to suggest patterns not otherwise discernible. NSF has pioneered and sustained the creation of indicators for science policy and has recently suggested monitoring several new indicators (e.g., indicators of proposal success rates, PI success rates, and continuity of NSF support).[116]

OTA agrees that new indicators could be very useful, and also suggests elaborating them. These could include measures of the active research community (which would calibrate the number of researchers actively engaged in research), and production units (which would track trends in the composition of research teams by broad field and subfield).

The combination of such indicators would give a more precise estimate of the changing parameters of the Federal research system.[117] This information would be invaluable to policymakers concerned about the health of certain sectors of the system. To produce such information, as part of ongoing agency data collection and NSF responsibilities for collation and presentation, extra resources would be needed (at least in the near term). Over time, plans could be developed to streamline NSF data and analysis activities, such as a reduction in the number of nonmandated reports issued annually, or expansion of its inhouse and extramural "research on research." The idea is not merely to *add* to data collection and analysis, but to substitute for current activities that are not used for internal agency decisionmaking or external accountability.[118] If there is a premium on timely information for research decisionmaking, it must be declared (and funded as) a Federal priority.

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[115] For example, see U.S. Department of Energy, Office of Program Analysis, Office of Energy Research, *An Assessment of the Basic Energy Sciences Program*, DOE/ER-0123 (Washington, DC: 1982). For a review of other evaluations, see National Academy of Sciences, Committee on Science, Engineering, and Public Policy, *The Quality of Research in Science* (Washington, DC: National Academy Press, 1982), app. C.

[116] National Science Foundation, "NSF Vital Signs: Trends in Research Support, Fiscal Years 1980-89," draft report, Nov. 13, 1990. Some of the indicators reported here were used for an inhouse National Science Foundation evaluation of ways to streamline the workload of program staff and the external research community. See National Science Foundation, *Report of the Merit Review Task Force*, NSF 90-113 (Washington, DC: Aug. 23, 1990).

[117] For example, what would be the indications that growth in research productivity is slowing or that the size of a research community is precariously large or small relative to the resources supporting it? See Colleen Cordes, "Policy Experts Ask a Heretical Question: Has Academic Science Grown Too Big?" *The Chronicle of Higher Education*, vol. 37, No. 3, Nov. 21, 1990, pp. A1, A22.

Congress could instruct every research agency to develop a baseline of information, direct NSF to expand its focus and coordinating function for data collection and analysis, and direct OSTP (in conjunction with OMB) to devise a plan to increase the reporting and use of agency data in the budget process, especially crosscutting information in priority research areas. Using the FCCSET mechanism, this has already been done for global change, high-performance computing, and most recently, science and mathematics education.[119] This mechanism seems to work and could be more widely emulated.

In summary, better data on the Federal research system could be instrumental in the creation or refinement of research policies for the 1990s. (For a summary of data oriented to different users, see table 1-5.) The utility of data, of course, is judged by many participants in the system: the needs of Congress are usually agency- and budget-specific;[120] the agencies, in contrast, worry about the performance of various programs and their constitutent research projects. While data collection by NSF and groups outside the Federal Government has been instructive, it could be greatly enhanced. Much information could be collected on the Federal research system that maps trends, at different levels of aggregation and units of analysis, for different users. However, the existence of data does not ensure their utility.

The highest priority in data collection for research policymaking in the 1990s is comparable data from all of the agencies to help Congress maintain a well-rounded view of federally supported research. The second priority is data presented in forms that are instructive at various levels of decisionmaking. New data and indicators, grounded in the tradition of the SEI volumes and extramural research on research, are needed to monitor changes in the Federal research system.[121] Finally, OTA finds that research evaluation techniques, such as bibliometrics and portfolio analysis, cannot replace judgments by peers and decisionmakers, but can enrich them. Ongoing project evaluation could keep agencies alert to changes in research performance and augment program manager judgments about performers and projects. In short, such evaluation could serve to improve overall program effectiveness.

One of the functions of analysis is to raise questions about the information that decisionmakers have at their disposal, to assess its advantages and disadvantages, and to define a richer menu of options.[122] Improving the measurement process could help to quantify existing opportunities and problems, and pinpoint previously uncovered ones, relevant to decisionmaking at all levels of the Federal Government.

Toward Policy Implementation

Since the post-Sputnik era, both the U.S. capacity to perform research and the demand for funds to sustain scientific progress have grown. Federal investments have fostered the research system, managed through a pluralistic agency structure. This structure has supported the largest and most produc-

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[118] The National Science Foundation routinely conducts ''user surveys.'' If Science Resources Studies (SRS) knows from questionnaire responses how its various data reports are used—do they influence research or education policies? are they a source for administrators or faculty-researchers?—then NSF should have a sense of audience ''consumption'' and ''utilization'' patterns. These would suggest *which* reports could be dropped, replaced, and modified. For an example of the SRS inventory of ''intramural publications,'' see National Science Foundation, *Publications List: 1977-1987*, NSF 87-312 (Washington, DC: July 1987).

[119] OTA interview with Office of Management and Budget staff, Feb. 7, 1991.

[120] As several National Science Foundation staff have indicated to OTA project staff (personal communications, October-December 1990), the Science Advisor draws heavily on unpublished and newly published *Science & Engineering Indicators* (SEI) data in preparing and presenting the Administration's policy proposals at congressional ''posture hearings'' early in the annual authorization process. Indeed, the production cycle of SEI is geared to delivery of the volume as an input to this budget process.

[121] Quantitative data will not suffice. Information on the contexts in which research is performed, and characteristics of the performers individually and collectively, will provide clues to how the numbers can be interpreted and perhaps acted on. For example, see Daniel T. Layzell, ''Most Research on Higher Education Is Stale, Irrelevant, and of Little Use to Policymakers,'' *The Chronicle of Higher Education*, vol. 37, No. 8, Oct. 24, 1990, pp. B1, B3.

[122] This leads OTA to suggest that the research agencies, especially the National Science Foundation and its policy programs, remain in close touch with external analysts of the Federal research system. Keeping abreast of other new measurement techniques and findings related to people, funding, and research activities would be a modest but fruitful investment in extending inhouse capabilities and refining knowledge of federally sponsored research performance.

Table 1-5—Desired Data and Indicators on the Federal Research System

Category	Description	Method	Primary users			
			Congress	Agencies	OMB	OSTP
Agency funding allocation method	Funding within and across fields and agencies Cross-agency information on proposal submissions and awards, research costs, and the size and distribution of the research work force supported	Agency data collection (and FCCSET)	X		X	X
Research expenditures	Research expenditures in academia, Federal and industrial laboratories, centers, and university/industry collaborations Agency allocations of costs within research project budgets, by field Megaproject expenditures: their components, evolution over time, and construction and operating costs	Agency data collection	X	X	X	
Research work force	Size and how much is federally funded Size and composition of research groups	Lead agency survey	X	X		X
Research process	Time commitments of researchers Patterns of communication among researchers Equipment needs across fields (including the fate of old equipment) Requirements for new hires in research positions	Lead agency survey; onsite studies		X		
Outcome measures	Citation impacts for institutions and sets of institutions International collaborations in research areas Research-technology interface, e.g., university/industry collaboration New production functions and quantitative project selection measures Comparison between earmarked and peer-reviewed project outcomes Evaluation of research projects/programs	Bibliometrics; surveys of industry and academia	X	X		X
Indicators	Proposal success rate, PI success rate, proposal pressure rates, flexibility and continuity of support rates, project award and duration rate, active research community and production unit indices	Agency analysis	X	X		X

KEY: FCCSET=Federal Coordinating Council on Science, Engineering, and Technology; OMB=Office of Management and Budget; OSTP=Office of Science and Technology Policy; PI=principal investigator.

SOURCE: Office of Technology Assessment, 1991.

tive research capability in the world. For many decades, scientific research has contributed in important ways to the cultural, technological, and economic base of the Nation.

In the 1990s, changing funding patterns and various pressures from both outside and within the scientific community will test the Federal research system. In such an environment, the prospects of fashioning a system that is responsive to national needs through selective, yet generous research funding will demand well-informed, coherent policies.[123]

The system will face many challenges, but four are clear: First, new methods of setting priorities and increased use of existing methods are required at all levels of decisionmaking. Second, Federal expenditures for individual components of research projects have increased faster than inflation. Understanding and coping with these increases is imperative in research decisionmaking. Third, the development of human resources for the science and engineering work force must occur through Federal incentives and institutional programs that act on the educational pipeline (K-12 through graduate study). Finally, gaps and uncertainties in the data used to describe the Federal research system must be reduced, and be replaced by more routine provision of policy-relevant information.

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[123] As Brooks has observed: "The research enterprise is more like an organism than like a collection of objects. The removal of one part may degrade the functioning of the whole organism and not just the particular function ostensibly served by the part removed." Harvey Brooks, "Models for Science Planning," *Public Administration Review*, vol. 31, May/June 1971, p. 364. Policies must respond to, and in some ways, anticipate, the consequences of funding decisions on the research system. Indeed, this report has tried to warn about extrapolating the past to manage the future of the system.

OTA finds that Congress, the executive branch, and research performers must converge on these issues. Potential congressional actions fall into three categories. Congress can: 1) retain primary responsibility for decisions and initiating actions; 2) place some of the responsibility for coordination and decisions on the executive branch; and 3) encourage research performers (especially universities, as well as Federal and industrial laboratories) to address components of these issues. (For a summary of possible actions, see table 1-6.)

At the congressional level, hearings, legislation, and oversight should first address crosscutting and within-agency priority setting at the national level. OTA suggests that one or more committees of Congress routinely (preferably biennially) hold hearings that require the research agencies, OSTP, and OMB to present coordinated budget plans with analyses that cut across scientific disciplines and research areas. Coordination among relevant committees of Congress would make this most productive. These hearings could also focus on crosscutting criteria for research decisionmaking within and across agencies. Emphasis must be placed on criteria to expand the future capabilities of the research system, such as strengthening education and human resources. A second set of congressional actions could explore cost-accountability efforts at the research agencies and throughout the research system. A final set of hearings ought to examine the state of data on the research system and improvements to inform congressional decisionmaking.[124]

Table 1-6—Summary of Possible Congressional, Executive Branch, and Research Performer Actions

Congressional hearings, legislative efforts, and oversight to:	• Set priorities across and within agencies, and develop appropriate agency missions. • Evaluate the total portfolio to see if it fulfills national research goals, human resources needs, scientific infrastructure development, and balance. • Initiate greater cost-accountability throughout the Federal research system. • Expand programs that fortify the educational pipeline for science and engineering, and monitor the combined contributions of agency programs to achieve education and human resources goals. • Augment data and analysis on the Federal research system for congressional decisionmaking.
Executive branch actions to:	• Enhance cross-agency priority setting in the Federal budget and increase research agency flexibility to address new priorities. • Institute better cost-accountability and cost-containment measures by agencies and research performers. • Expand agency programs to promote participation in the educational pipeline for science and engineering, and require agencies to report progress toward these goals. • Monitor and analyze policy-relevant trends on the research system, especially as related to the changing organization and productivity of research groups and institutions.
Research performer actions to:	• Contain and account for research expenditures. • Revise education and research policies as they affect: a) recruitment and retention in the educational pipeline for science and engineering, and b) faculty promotion, tenure, and laboratory practices.

SOURCE: Office of Technology Assessment, 1991.

Hearings could be followed with congressional oversight—on agency progress toward their research missions, implementing the criteria chosen by Congress to enhance research decisionmaking, instituting greater cost-accountability, and providing useful data and analysis on an ongoing basis to Congress.

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[124] There is a role for the congressional support agencies, as well as other sources of expert advice. For other proposals, see Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Congress: Expert Advice and the Decisionmaking Process* (New York, NY: February 1991).

Some of these hearings and oversight efforts already take place in committees of Congress. While they have been very useful, OTA finds that to effect change in the research system, congressional action must be comprehensive and sustained. Posture hearings with the Science Advisor and agency directors will not suffice.

In its role as the prime sponsor of Federal research, the executive branch (especially OSTP, OMB, and the research agencies) could provide more flexibility in response to changing research priorities. For instance, the executive branch could systematically initiate tradeoffs among agency research programs including, with the cooperation of Congress, the *termination* of programs. This would help to create more coordinated research policies. Similarly, the research agencies could institute greater cost-accountability measures, and include costs as explicit factors in decisionmaking at the project level. This would provide a more realistic assessment of future capabilities with respect to projected funding levels. On human resources issues, the executive branch could implement or expand agency programs and reporting requirements to: 1) encourage recruitment and retention of women, U.S. minorities, and other underparticipating groups in the educational pipeline for science and engineering; and 2) monitor the changing structure of research performance, especially forms of research organization, and devise funding allocation methods that accommodate both the needs of the PI and research teams. Finally, each of the research agencies (with NSF as the lead agency) could conduct routine data collection and analysis on policy-relevant aspects of their programmatic contributions to the research system.

Not all problems in the research system, however, can be addressed in Congress or by the executive branch. Universities and laboratories (both Federal and industrial) are key components of the system, and many policies are dictated by the practices within these institutions. Containing research expenditures and expanding the educational pipeline through institutional programs and requirements are examples of policy areas in which research performers must fulfill their role in the social contract implied by the Federal patronage of research. The Federal Government can only encourage universities and laboratories to follow new paths; few direct Federal incentives are available to initiate change. Greater delineation of government and research performer responsibilities would help to sanction congressional and executive branch action on problems in the research system.

Photo credit: Jay Mangum Photography

Communication among scientists and engineers is an essential part of the research process.

In addition to specifying at which level (congressional, executive branch, or research performer) issues could be appropriately addressed, responses to the four challenges outlined above must also recognize many inherent tensions in the research system. They include the merits of more centralized decisionmaking juxtaposed against the advantages (and realities) of a decentralized Federal research system. Other tensions arise between the funding of mainstream individual investigator programs and set-aside or more specialized programs (see again table 1-1). Inevitably, policies that relieve some tensions will engender others.

In summary, decisionmaking in the Federal research system concerns many laudable goals, and the options are clearly competing "goods." Thus, the Federal Government must make tough choices, even beyond issues of merit and constricted budgets, in guiding the research system. A quarter-century ago, a chapter on "Science and the Federal Government" concluded with these words:

> As never before in history, the status of science and technology has become an important hallmark of a nation's greatness; and the United States clearly has perceived and acted upon this fact. In the process, the Federal Government has displaced the university, industry, and the private foundation as chief patron and has fashioned a host of institutions to administer vastly increased commitments to scientific and technological excellence.[125]

Sustaining and managing this system is the challenge of the decade ahead.

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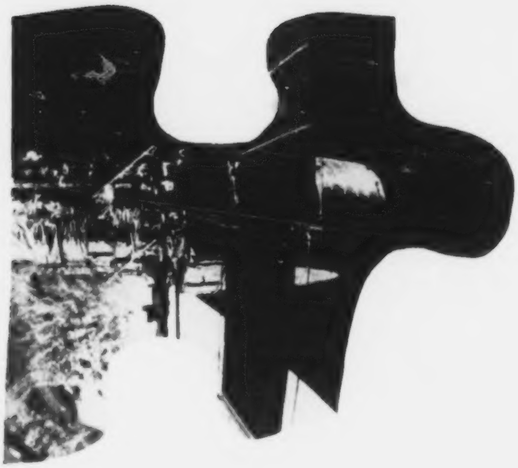
[125] Cited in Ralph Sanders and Fred R. Brown (eds.), *Science and Technology: Vital National Assets* (Washington, DC: Industrial College of the Armed Forces, 1966), p. 86.

CHAPTER 2

The Value of Science and the Changing Research Economy



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CHAPTER 2

The Value of Science and the Changing Research Economy

> *This is a golden age of scientific discovery with great potential to improve our performance as a Nation. This is the rationale we use in our requests for increased funding. But even a country as rich as the United States cannot write a blank check for science. We need to discipline ourselves in how we request support and in how much we ask for. Otherwise we will lose our credibility.*
>
> Frank Press[1]

Introduction

Research advances the world stock of scientific knowledge and the countries that finance its pursuit. The United States, in particular, has a history of strong support of research and belief in its inherent worth. Scientific discoveries have spurred technological and other kinds of developments since the beginning of the industrial age, and thus have shaped much of Western culture. Cures to diseases have been found, better automobiles and space probes have been developed, the Earth and its environments more fully understood, and the foundations of atomic matter explored.

The importance of science to progress in most Western societies is indisputable. In the words of two economic historians:

> Science . . . is pushing back the frontiers of knowledge at what seems an accelerating pace. Because knowledge creates economic resources and because knowledge generally grows at an exponential rate, future advances in human welfare can be at least as striking as those of the past two hundred years.[2]

In the United States, scientific and engineering research has a significant impact on the products and processes that fuel U.S. economic growth and productivity.[3] There is also ample recognition of the significant role played by the Federal Government in legitimizing and financing research as a public good.[4] (This is epitomized by the case of superconductivity, see box 2-A.) Such findings are reassuring that, in the words of science policy statesman

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[1] "NAS Annual Meeting: Kudos From George Bush, Challenges From Frank Press," *NewsReport of the National Research Council*, vol. 40, June 1990, p. 8.

[2] Nathan Rosenberg and L.E. Birdzell, Jr., "Science, Technology and the Western Miracle," *Scientific American*, vol. 263, No. 5, November 1990, p. 54.

[3] Reporting the results of a new empirical investigation, economist Edwin Mansfield finds: ". . . that about one-tenth of the new products and processes commercialized during 1975-85 in . . . [seven] industries could not have been developed (without substantial delay) without recent academic research. The average time lag between the conclusion of the relevant academic research and the first commercial introduction of the innovations based on this research was about seven years. . . . A very tentative estimate of the social rate of return from academic research during 1975-78 is 28 percent, a figure that is based on crude (but seemingly conservative) calculations and that is presented only for exploratory and discussion purposes. It is important that this figure be treated with proper caution. . . . Our results . . . indicate that, without recent academic research, there would have been a substantial reduction in social benefits." See Edwin Mansfield, "The Social Rate of Return From Academic Research," *Research Policy*, forthcoming 1991.

Another analysis, using different measures, supplements Mansfield's finding. While knowledge is found to be a major contributor to productivity growth, there is roughly a 20-year lag between the appearance of research in the academic community and its effect on productivity as measured by industry-absorbed knowledge. See James D. Adams, "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, vol. 98, No. 4, 1990, pp. 673-702. Of course, during the 20-year gestation period, much applied research and development must occur before the effects on industrial productivity are realized. Economists find Mansfield's empirical approach the most direct evidence of economic returns to date. Summary of reactions at American Economic Association and National Science Foundation seminars in 1989 and 1990 provided by Leonard Lederman, personal communication, January 1991. For a discussion of measurement techniques, see ch. 8.

[4] Indeed, the U.S. research system is designed so that returns on Federal investment will accrue to the private sector and other nations. The results of publicly funded research are for the most part openly disseminated with little or no copyright protection or patent exclusivity. For how this situation is changing, see U.S. Congress, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and Information*, OTA-CIT-302 (Washington, DC: U.S. Government Printing Office, April 1986). Also see Congressional Budget Office, "Federal Investment in Intangible Assets: Research and Development," unpublished document, February 1991.

Box 2-A—History of Superconductivity: Scientific Progress Then and Now

The history of superconductivity illustrates the episodic nature of progress in scientific research and the limitations of predictions for scientific advancement in a specific research area. Due to resistance, normal conductors will lose energy in the form of light or heat when a current is passed through them. While this is not a wholly undesirable effect (e.g., in heaters and light bulbs), in most electric applications, resistance wastes energy. Successfully harnessing the resistance-free currents of superconductors could be revolutionary: energy could be transmitted with perfect efficiency; electronic devices could be made faster and smaller; and the power of superconducting magnets (many of which are much stronger than traditional electromagnets) could transform traditional transportation methods both on land and at sea.[1] The first superconductor was discovered in 1911 by Kammerlingh Onnes, a Dutch scientist. Using liquid helium, Onnes cooled mercury to 4 degrees Kelvin (K) above absolute zero,[2] at which point an electric current flowing through the mercury suddenly lost all resistance (for a chronology of subsequent progress, see figure 2A-1).

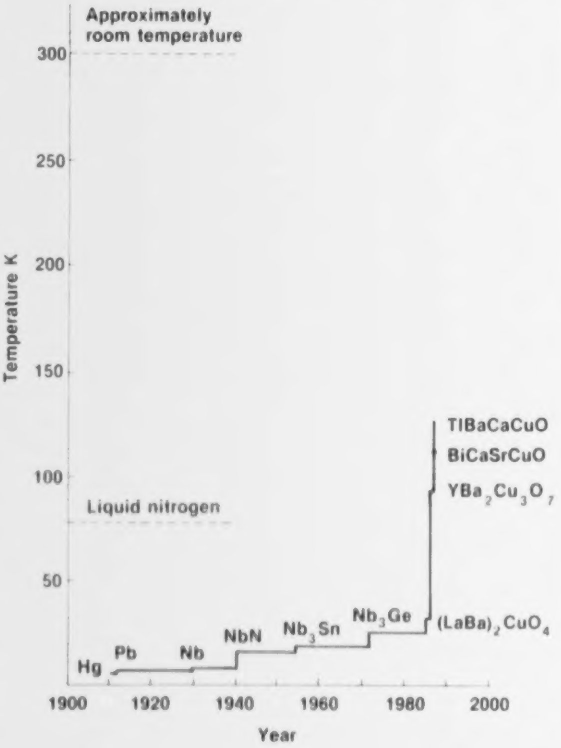
The Science of Superconducting Materials

Limitations on the physical properties required for a material to superconduct have hindered widespread applications. For every superconducting material there is a threshold for its physical properties (temperature, magnetic field level, and current density) above which it will not superconduct. By the 1950s, researchers had discovered many materials that would superconduct, but at temperatures no higher than about 20 K.

The 1950s brought two separate breakthroughs that moved superconductivity closer to applicability. First, researchers in the Soviet Union discovered a new class of superconductors that would remain superconducting in high magnetic fields, and that could eventually be used in superconducting magnets. Second, in 1957, the American research team of Bardeen, Cooper, and Schreiffer received the Nobel prize and recognition for a theory explaining superconductivity.

From the 1950s to the early 1980s, progress toward higher temperature superconductors was slow. Then, a surprising breakthrough occurred in late 1986 that transformed superconductivity research and drew widespread public attention. In Zurich, the IBM research team of Bednorz and Mueller discovered a new ceramic material that remained superconducting at temperatures as high as 35 K. A few months later in 1987, a research team at the University of Houston developed a similar ceramic material that could superconduct at 92 K. Not only did these discoveries provide the long-awaited ability to use liquid nitrogen instead of helium as a coolant, the discoveries were made at such an incredible pace, considering the history of superconductivity research, that the goal of room-temperature superconductivity (at roughly 300 K) suddenly appeared to be within reach.

Figure 2A-1—Superconducting Critical Transition Temperature v. Year



SOURCE: U.S. Congress, Office of Technology Assessment, *High-Temperature Superconductivity in Perspective*, OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990), figure 2-3.

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[1] For a more comprehensive description of applications for superconductivity see U.S. Congress, Office of Technology Assessment, *High-Temperature Superconductivity in Perspective*, OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990).

[2] One degree Kelvin (K) is equal to one degree Celsius (°C), except that Kelvin is measured from absolute zero (−273 °C). Room temperature (about 75 °F, or 25 °C) is about 300 K.

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The Federal Response

The response to these discoveries was enormous. The popular press lauded high-temperature superconductivity as ". . . the startling breakthrough that could change our world."[3] Scientific meetings where superconductivity results were rumored to be released became standing-room-only events.[4] While the temperature barrier still frustrates researchers, work continues in other areas that are key to useful applications of superconductivity, like current densities and magnetic fields. Success has been attained in many areas, but much more research needs to be done.

Fortunately, the Federal Government has maintained its commitment: in 1987, President Reagan presented an 11-point agenda to increase superconductivity research and development (R&D) in the United States, and in 1988, Congress enacted several laws pertaining to superconductivity R&D, mostly aimed at spurring commercial development of superconducting technologies. The Federal superconductivity budget rose from $85 million in fiscal year 1987 to $228 million in fiscal year 1990, with most of the increase going to high-temperature research.[5] Funding is spread among several different agencies, primarily the Departments of Defense (DOD), Energy, and Commerce, the National Science Foundation, and the National Aeronautics and Space Administration. Programs at different Federal agencies have aided scientists in the exchange of research information.[6]

Photo credit: U.S. Department of Energy

A magnet is levitated by high-temperature superconducting materials that are cooled in liquid nitrogen. Superconducting materials may eventually levitate much larger bodies, such as magnetically levitated trains. Superconductivity is a research area that may yield many fruitful applications.

Congress has made several attempts to coordinate superconductivity research. Part of the 1988 Omnibus Trade and Competitiveness Act created the National Commission on Superconductivity (NCS). The Trade Act also mandated an increase in staff for the National Critical Materials Council (NCMC). Finally, the National Superconductivity and Competitiveness Act of 1988 called for cooperation among the Office of Science and Technology Policy (OSTP), NCMC, and NCS in order to produce a 5-year National Action Plan for Superconductivity to be accompanied by annual reports. The success of these initiatives has been limited. The 5-year National Action Plan was published in December of 1989, but the formation of NCS was delayed. Although the plan itself acknowledged the need for better Federal coordination, it lacked both the budget recommendations and the long-term perspective Congress had requested.[7] In addition, OSTP's Federal Coordinating Council on Science, Engineering, and Technology Committee on Superconductivity report of March 1989 did little more than assemble agency superconductivity budget data and list programs in the agencies.[8]

Questions remain, such as whether DOD funds too high a percentage of superconductivity research and whether the Federal laboratories are doing too much of the research relative to other performers. Progress in the development of high-temperature superconductivity is likely to unfold slowly—with substantial assistance from the Federal Government.

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[3] Michael D. Lemonick, "Superconductors!" *Time*, May 11, 1987, p. 64.

[4] Phil Adamsak, "A Super Year in Science," *Visions*, fall 1987, p. 20.

[5] Office of Technology Assessment, op. cit., footnote 1, p. 63.

[6] The Ames laboratory distributes the "High-T_c Update," a widely read newsletter; the national laboratories have broadcast nationally several high-temperature superconductivity conferences; and the Department of Energy has established a computer database that shares research results with industry. The National Aeronautics and Space Administration also maintains a Space Systems Technical Advisory Committee, a group with representatives from industry, universities, and government organizations.

[7] Office of Technology Assessment, op. cit., footnote 1, p. 63.

[8] Ibid., p. 69.

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Harvey Brooks: ''A strong basic science is a necessary condition for a strong economy, a livable environment, and a tolerable society.''[5]

Survey results indicate that since the mid-1970s public confidence in the scientific community ranked second only to medicine and ahead of 11 other social institutions, including education, the press, and Congress.[6] Furthermore, the expectations of the American public about science and technology during the next 25 years include cures for cancer and AIDS, safe long-term storage or disposal of wastes from nuclear powerplants, establishment of a colony on the Moon, and development of genetically engineered bacteria to destroy toxic chemicals. But among the same sample of adults, realism about the possible negative consequences of science and technology is clearly evident. More than two in five respondents considered another Three Mile Island-type accident and the accidental release of a toxic chemical that results in numerous deaths of Americans ''very likely.''[7] Finally, when asked their preference for problems that should receive more Federal funding, three of four Americans responded ''helping older people,'' ''improving education,'' and ''reducing pollution,'' two of three noted ''improving health,'' one in two favored ''helping low income people,'' and one of three responded ''scientific research'' (which was well ahead of ''exploring space'' and ''improving defense'').[8] For further discussion of Federal funding in the ''public interest,'' see box 2-B.

Taken together, the investments and expectations of the Federal Government in research have contributed to a shining history of scientific advance in the United States. Universities, Federal laboratories, and industrial research centers have discovered many new phenomena and developed theories and techniques for their continued exploration and use. In the 1990s, preserving quality in research, while understanding changes in the political and economic environment in which it has grown, will require planning and adaptation by research sponsors and performers alike.

Research Funding in the United States

Focusing on research (*not* development), as OTA does in this report, reduces the scope, but not the complexity of the Federal research system.[9] The Federal Government spent over $11 billion in fiscal year 1990 on basic research and over $10 billion on applied research. Research thus represents 1.8 percent of the total Federal budget (at $1.2 trillion). This 1.8 percent, or roughly $21 billion, is an abstraction referred to as the ''Federal research budget.''[10]

Funding for research in the United States is led by the Federal Government (47 percent of the national total). Industry is a close second at 42 percent; universities and colleges (the category that includes State and local government funds) follow at 7 percent; nonprofit institutions and others fund the remaining 4 percent. Industrial support of basic and applied research has grown dramatically over the

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[5] Harvey Brooks, ''Can Science Survive in the Modern Age?'' *Science*, vol. 174, Oct. 1, 1971, p. 29. Brooks goes on to caution that a strong basic science is not a *sufficient* condition. For a recent postscript, see Harvey Brooks, ''Can Science Survive in the Modern Age? A Revisit After Twenty Years,'' *National Forum*, vol. 71, No. 4, fall 1990, pp. 31-33.

[6] The question asked was: ''As far as the people running these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?'' Since 1973, from 37 to 45 percent of the respondents indicated ''. . . a great deal of confidence.'' See National Science Board, *Science and Engineering Indicators—1989*, NSB 89-1 (Washington, DC: 1989), p. 172 and app. table 8-11.

[7] Respondents in 1985 were asked: ''Do you think it is very likely, possible but not too likely, or not at all likely that this result will occur in the next 25 years?'' National Science Board, *Science and Engineering Indicators—1987*, NSB 87-1 (Washington, DC: 1987), p. 150 and app. table 8-10.

[8] The respondents were asked to tell, for each problem, ''. . . if you think that the government is spending too little money on it, about the right amount, or too much.'' See National Science Board, op. cit., footnote 6, p. 174 and app. table 8-13. A sample of British respondents were asked the same question in 1988. Improving health care and helping older people topped their list, while 47 percent (v. 34 percent of the U.S. sample) expressed a desire for increased government funding of scientific research.

[9] In empirical terms, ''research'' has changing referents in the report. Sometimes a measure refers to ''academic'' or ''university'' research, other times to ''basic'' research. The reader is alerted to these different performers or activities as OTA reviews them and the sources of information used to characterize scientific research.

[10] The research figures are current dollar estimates. See Albert H. Teich et al., *Congressional Action on Research and Development in the FY 1991 Budget* (Washington, DC: American Association for the Advancement of Science, 1990). Other figures are computed from various sources cited in table 1-2.

Box 2-B—Public Interest in Science

At a time when U.S. society has embarked on more technological adventures than ever before, Americans apparently understand less about science and technology than citizens in other western countries. But understanding alone is not the issue; rather, it is the complex relationship among public understanding, public confidence in science and technology, and the public interest.[1] From the turn of the century through World War II, American technology and science came into its own. New inventions for the benefit of consumers were talked about everywhere from the Sears and Montgomery Ward catalogs to popular magazines; stories about the new invention, the telephone, were plentiful; and even if not everyone understood the new technology, they had confidence in it.[2]

Military technology, given its lasting impact on everyone's lives during wartime, seemed easier to fathom "back then." Soldiers understood how a gun worked; stories abound about how American GI's were able to fix things on the spot, using whatever spare parts they could lay their hands on. People thought they understood the technology that surrounded them and that it was essentially beneficial.[3]

With the development of the atomic bomb (necessarily shrouded in secrecy) came the end of innocence. The shattering of Hiroshima and Nagasaki was accompanied, for many, by a shattering of faith in science and technology as forever benign and helpful. In ways that we have only now begun to understand, the image of destruction associated with the atom bomb has affected all technology, certainly all technology associated with nuclear power and nuclear waste. With Three Mile Island, Bhopal, the Challenger accident, and Chernobyl, this image of destruction has become the paradigm, for many, of all science and technology.[4]

The discovery of restriction enzymes that slice strands of DNA into separate pieces, and that DNA pieces from different species will connect with each other, has given rise to the great hope of understanding and curing genetic diseases. Yet it also has raised fears of somehow disturbing the natural universe, changing things that ought not be tinkered with. To know more sometimes is to fear more: "unintended consequences" is today a familiar refrain; even good intentions have side effects.

The very advance of biological and medical knowledge itself leads to frustrations and contradictions, further undermining confidence in science. If we can perform the miracle of organ transplants, why can we not cure multiple sclerosis? If we can cure childhood leukemia, why not lung cancer? *Science* editor Daniel E. Koshland writes:

> But as architects of change, we [scientists] have occasionally oversold the product, implying that it will bring unmixed good, not acknowledging that a scientific advance is a Pandora's box with detriments or abuses as well as benefits. By confessing that we are not omniscient we may lose some awe and admiration, but we will gain in understanding and rapport.[5]

What can the scientific community do? Despite some negative feeling about science, or some aspects of it, there are indications that the public is more interested in it and more willing to make the effort to learn than they are given credit for. Although 20 percent of college graduates earn science and engineering degrees, many more enter college eager to learn science.[6] The television program "Nova," which covers all aspects of science, is consistently among the more highly watched programs on public television. And 95 daily newspapers across the Nation have weekly

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[1] This box is adapted from Alan H. McGowan, president, Scientists' Institute for Public Information, who wrote it expressly for this OTA report under the title "Public Understanding of Science." For an overview of the relationship between public interest, understanding, and confidence, see Kenneth Prewitt, "The Public and Science Policy," *Science, Technology, & Human Values*, vol. 7, spring 1982, pp. 5-14.

[2] One of the best descriptions of this phenomenon is to be found in Daniel J. Boorstin, *The Americans: The Democratic Experience* (New York, NY: Vintage Books, 1974).

[3] There is a difference between understanding the scientific principles behind an invention or technology and having a general idea of how the parts fit together or what sequence of events must occur to make the technology work.

[4] See Daryl E. Chubin, "Progress, Culture, and the Cleavage of Science From Society," *Science, Technology, and Social Progress*, S.L. Goldman (ed.) (Bethlehem, PA: Lehigh University Press, 1989), pp. 177-195; and "Is Knowledge a Dangerous Thing?" *The Economist*, vol. 318, Feb. 16, 1991, pp. 21-22.

[5] Daniel E. Koshland, "To See Ourselves As Others See Us," *Science*, vol. 247, Jan. 5, 1990, p. 9. For a content analysis of how popular magazines portrayed science in the first half of the 20th century, see Marcel C. LaFollette, *Making Science Our Own: Public Images of Science 1910-1955* (Chicago, IL: University of Chicago Press, 1990).

[6] U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988), ch. 1.

Continued on next page

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Box 2-B—Public Interest in Science—Continued

science sections which, according to their editors, are among the most highly regarded sections in the paper. This represents a growth from 66 such sections in 1986 and 19 in 1984.[7]

The attitude in the scientific community has also changed. Fifteen years ago, most scientists avoided the popular press. Now, many scientists and engineers relish being quoted.[8] Still, working to improve public understanding is not rewarded in many ways within the scientific community; the time is taken from other pursuits, and therefore can be costly to one's career.[9]

What mechanisms would encourage more involvement by scientists and engineers in raising public interest in and understanding of science efforts? Congress might include required spending of a portion of research grants on public understanding efforts, designating a fraction of each agency's budget for an office devoted to help grantees develop public understanding efforts, and giving awards to scientists who have made substantial contributions to public understanding.[10] At a time when more and more of American life is rooted in science and technology, and when the Nation's economic well-being depends as never before on its understanding and utilization, the Federal Government cannot be complacent about the public's interest and confidence in science.[11]

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[7] "Newspaper Science Sections Still on the Rise," *SIPIscope*, vol. 18, spring 1990, p. 1. As one science policy statesman writes: "I have come to believe . . . that the way things will work out for American science is very much in the hands of communicators—of science writers and reporters. They are a breed of science watchers, and the last thing in science's interests is to patronize or condescend to them." William D. Carey, "Scientists and Sandboxes: Regions of the Mind," *American Scientist*, vol. 76, March-April 1988, p. 144. Also see Maurice Goldsmith, *The Science Critic* (London, England: Routledge & Kegan Paul, 1986).

[8] In addition, as sociologist Dorothy Nelkin puts it: "Dependent more on political choices than peer review, many scientists in the 1980s became convinced that scholarly communication was no longer sufficient to assure support for their costly enterprise, that national visibility through the mass media was strategically essential. They greatly expanded efforts to work the media, trying to shape the images conveyed." Dorothy Nelkin, "Selling Science," *Physics Today*, November 1990, p. 45. Also see the special issue in which this article appears, "Communicating Physics to the Public," *Physics Today*, November 1990, pp. 23-56.

[9] See Neal E. Miller, *The Scientist's Responsibility for Public Information* (New York, NY: Scientists' Institute for Public Information, Media Resource Service, 1990); and John P. Donnelly, "Researchers Must Join Forces to Bolster Public Confidence and Funding Support," *The Scientist*, vol. 4, No. 20, Oct. 15, 1990, p. 16.

[10] Precedents for such activities include a 1-percent set-aside in the budgets of the National Institutes of Health (NIH) for evaluation of NIH research, and the annual "Public Understanding of Science and Technology" awards given to science journalists by the American Association for the Advancement of Science and Westinghouse.

[11] Greater public understanding of science will not necessarily lead to greater Federal funding of research. As one commentator observed a generation ago: "Although there is no question that the public has demonstrated its willingness to provide . . . support, I doubt whether the intrinsic cultural value could be used to justify to the public or to politicians more than a small fraction of the present support for basic science in the United States, or indeed in any other major country of the world." Harvey Brooks, "Are Scientists Obsolete?" *Science*, vol. 186, Nov. 8, 1974, p. 508.

last 20 years, especially in the early and mid-1980s.[11] For basic research alone, the Federal Government funds 62 percent of the total, followed by industry (21 percent), universities and colleges (12 percent), and nonprofit institutions and others (5 percent).[12]

While questions of relative funding can be gauged with funding data (e.g., comparisons between Federal and industrial support), it is not easy to compare expenditures in one year to those in another. Economic change affects the "value" of a dollar over time. Because some goods (foodstuffs, automo-

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[11] The national *R&D* effort is funded primarily by the Federal Government, industry, and academic institutions. In 1990, industry and the Federal Government together accounted for nearly 96 percent of total support, with universities and colleges contributing 3 percent, and other nonprofit institutions funding 1 percent. Industry is the largest single source of R&D funds, providing $74 billion compared to the Federal Government's $69 billion, and the past decade represents a period of great growth in industrial R&D spending. National Science Foundation, *National Patterns of R&D Resources: 1990*, NSF 90-316 (Washington, DC: May 1990), table B-5.

[12] For these aggregate figures, the National Science Foundation estimates of basic/applied/development breakdowns—despite some fuzziness in labeling—are thought to be reliable. See ibid.

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Photo credit: Jay Mangum Photography

This research is part of an acid rain study in the Duke Forest Project, NC. Research can take many forms, from space exploration to the study of microbes, and almost all are represented in the Federal research portfolio.

biles, housing) change slowly over time, economists have developed so-called constant dollars or "deflators" to use in comparing economic activity in two or more years. Constant dollars work less well for goods that change rapidly (e.g., computers, consumer electronics, and defense technologies), and not at all for products that, by definition, are dissimilar from one year to the next.[13] The use of any two deflators can also lead to very large differences, especially as the timeframe lengthens. Taking into account these difficulties in the use of deflators for comparing research funding over time, OTA has chosen to use the "Gross National Product Implicit Price Deflator." This deflator reflects changes in total public and Federal expenditures. Thus, OTA's figures can be easily compared, as Congress routinely does, with trends in other public expenses.[14] (Box 2-C discusses different deflators and their use in interpreting trends in research funding.)

Documenting Perspectives on the Future of Research

The American public holds scientific research in high esteem, but does not see it as the Nation's top priority. This contrasts with survey findings of the late 1980s and 1990 reflecting the perceptions of scientists and engineers. Biomedical researchers in academia and industry, recombinant DNA researchers, young faculty researchers in physics, and a cross-section of Sigma Xi (The Scientific Research Society) members all report difficulty in establishing or sustaining research programs and fear reductions in Federal funding for individual-investigator research (which they see as a *top* funding priority).[15] Perhaps the most forceful recent advocate of increased research funding is Nobel laureate physicist

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[13] In this construction, research is a "product," i.e., has measurable outputs. But the value of the output is not determined by market prices. It would be more accurate perhaps to treat research as a "process," i.e., an activity or service to the economy.

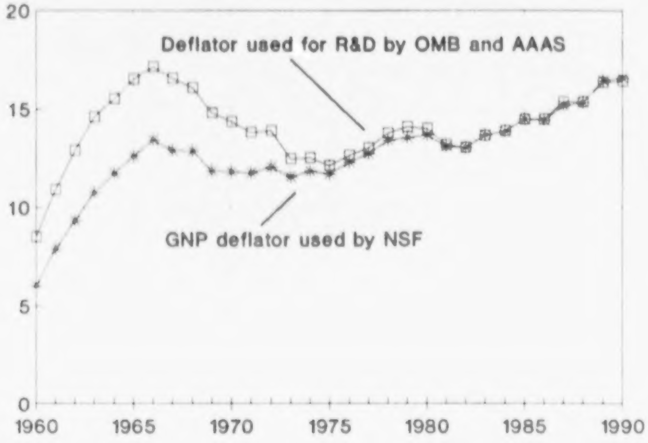
[14] The executive branch perspective is contained in the *Economic Report of the President* (Washington, DC: U.S. Government Printing Office, 1990).

[15] See, respectively, Gallup poll results reported by the Pharmaceutical Manufacturers Association Foundation, Inc., *Losing Ground in Biomedical Research: The Shortage of American Scientists* (Washington, DC: February 1991); Isaac Rabino, "The Impact of Activist Pressures on Recombinant DNA Research," *Science, Technology, & Human Values*, vol. 16, No. 1, winter 1991, pp. 70-87; American Physical Society survey results reported in Roman Czujko et al., "Their Most Productive Years: Young Physics Faculty in 1990," *Physics Today*, February 1991, pp. 37-42; and Political Economy Research Institute, "Researcher Perspectives on the Federal Research System," OTA contractor report, July 1990 (available through the National Technical Information Service, see app. F).

Box 2-C—Calculating Constant Dollar Trends for Research

While seeming a trivial problem at first glance, calculating funding trends for research in constant dollars (i.e., units that have the same spending power in each year) can be full of pitfalls. Different methods can lead to quite different trends and, therefore, policy conclusions. For example, the constant dollar values calculated using a method developed at the Department of Commerce (and used by the National Science Foundation) imply that research expenditures in the United States have grown by roughly 40 percent in the period 1969 to 1990. Similar calculations based on a method developed by the Office of Management and Budget (and used by the American Association for the Advancement of Science) imply that research expenditures have grown by less than 15 percent (see figure 2C-1).[1]

Figure 2C-1—Federal Research Spending in Constant Dollars Using Two Different Deflators: Fiscal Years 1960-90 (in billions of 1982 dollars)



KEY: R&D = Research and Development; OMB = Office of Management and Budget; AAAS = American Association for the Advancement of Science; GNP = Gross National Product; NSF = National Science Foundation.

SOURCES: Current dollar data came from National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1. Deflator data came from the Office of Management and Budget, Budget Analysis and Systems Division, unpublished data; and National Science Board, *Science and Engineering Indicators—1989*, NSB 89-1 (Washington, DC: 1989), app. table 4-1.

So how does one calculate a constant dollar trend? The object is to translate dollars from one year to the next, i.e., to find the price of a market basket of commodities. The deflator is the ratio of the purchasing power of a dollar for a particular year to that of a reference year. A change in the index means that purchasing power has changed with respect to the same market basket. This change can also be expressed as "constant dollars," such as "1982" or "1988" dollars. These ratios can then adjust any dollar amount for a given year to get a value in constant dollars.

A set of ratios or indices for a series of years is called a "deflator." To calculate a deflator, a comparison must be made between how much a specific thing costs in the year in question and in the constant dollar year. The differences between methods used to calculate constant dollar trends depend on what goods or services are tracked to make up the deflator. For instance, increasing salaries are very different from increasing (or decreasing) prices of computers.

Congress is most interested in comparing research expenditures to other elements of the Federal budget. Thus, a deflator that represents expenditures on products and services that are often bought throughout the United

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[1] Informal meeting on deflators, hosted by the American Association for the Advancement of Science, Dec. 5, 1990. OTA notes that the National Institutes of Health uses its own deflator, called the Biomedical Research and Development Price Index, which is discussed in ch. 6.

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States—a constant dollar in the most general sense—is often the most useful for congressional policy analysis. Using the Gross National Product (GNP) Implicit Price Deflator developed by the Department of Commerce is usually acceptable, since it employs a large market basket of goods to calculate its constant dollar ratios.[2] Constant dollar trends for research calculated with this deflator compare research expenditures to other expenditures throughout the economy.

In other contexts, a deflator that specifies indices relating only to research (salaries, facilities, and instrumentation) could be preferable. In such a deflator, if 45 percent of total expenditures for research goes to salaries,[3] 45 percent of the deflator would reflect the changes in these salaries. When other components of the deflator are similarly adjusted—equipment, facilities, and indirect and other costs—a new index is derived. Use of such an index to adjust total research expenditures would approximate how much scientists were spending in one year as if the prices and contents of the market basket of goods and services were unchanged (i.e., the effect of increasing salaries and cost of equipment and other items would have been removed).[4] Deflators are difficult to calculate for science and engineering research, because the items and mix of the market basket can change rapidly and they may be quite different in separate fields of inquiry. In addition, even a "correct" deflator of this type can be misleading because it only concerns inputs and not the changing character of research outputs, i.e., one is not buying the same science and engineering "product."

Given the problems with research-specific deflators and the advantage of a general GNP deflator to compare expenditures across the economy, all constant dollar figures and tables in this report were calculated with the GNP Implicit Price Deflator for 1982 dollars (unless noted otherwise). However, OTA does not make any specific policy assumptions based exclusively on constant dollar trends.

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[2] *Economic Report of the President*, Transmitted to Congress February 1990 (Washington, DC: U.S. Government Printing Office, 1990), pp. 298-299, table C-3.

[3] See ch. 6 of this report.

[4] No deflator has been created using this method. Bruce Baker, Office of Management and Budget, personal communication, Nov. 26, 1990. But see a pair of working papers by John E. Jankowski, Jr., National Science Foundation, "Do We Need a Price Index for Industrial R&D?" n.d.; and "Construction of a Price Index for Industrial R&D Inputs," Aug. 1, 1990. Among the approximations used is the Office of Management and Budget noncapital Federal expenditures deflator developed to normalize all expenditures of the Federal Government that do not involve the specific procurement of large, capital items—obviously a much larger set of expenditures than those involved in research. As stated by Bruce Baker, Office of Management and Budget: "This is *not* an R&D deflator, it is a deflator used to deflate R&D." American Association for the Advancement of Science, op. cit., footnote 1. The problem with the use of this deflator is that even though it excludes many expenditures unrelated to research, the expenditures that are reflected in the deflator are not guaranteed in any way to mimic research expenses over time. Consequently such a deflator may be just as "wrong" as any other deflator to calculate research productivity.

Leon Lederman, who also relies on a survey of active researchers in major universities (see box 2-D).

Such surveys can take the pulse of a population, tapping respondents' perceptions, experiences, and feelings. Other data, however, must be assembled and analyzed to provide a more systematic, well-rounded characterization of the state of affairs—and general health—of the Federal research system. That is OTA's objective in this report.

Although scientists may now feel engulfed by the stress of research competition, the Federal research system and the place of U.S. science in the world has remained strong. Other countries support research infrastructures at the forefront of many fields—which is expected in an internationally competitive economy—but U.S. science still ranks at or near the top in most fields. This is a testament to the strength and scale of federally funded research.[16]

This system will face many challenges in the 1990s, including living with tight fiscal conditions. In the 1980s, four categories of Federal spending consistently increased in constant dollars: defense, entitlements (Social Security, Federal retirement,

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[16] There is evidence that the United States is a latecomer to the stresses beleaguering other nations. See Susan E. Cozzens et al. (eds.), *The Research System in Transition*, proceedings of a NATO Advanced Study Institute, Il Ciocco, Italy, Oct. 1-13, 1989 (Dordrecht, Holland: Kluwer, 1990). The question of whether the United States is "losing ground" to other nations very much depends on which fields or research areas are of concern, and which indicators of research productivity one chooses to embrace. For evidence to the contrary, see Gina Kolata, "Who's No. 1 in Science? Footnotes Say U.S." *New York Times*, Feb. 12, 1991, pp. C1, C9; and "No Slippage Yet Seen in Strength of U.S. Science," *Science Watch*, vol. 2, No. 1, January/February 1991, pp. 1-2.

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Box 2-D—An Interpretation of Researchers' Distress by Leon M. Lederman

On January 7, 1991, Leon M. Lederman, Nobel laureate physicist and President-Elect of the American Association for the Advancement of Science (AAAS), sounded "a cry of alarm" for academic science. He released a report to the AAAS membership expressing concern ". . . for the future of science in the United States and for the profound cultural and economic benefits that science brings."[1] The following are excerpts from the report, which was based on an informal survey of natural sciences faculty in 50 U.S. universities, including the top 30 institutions in Federal R&D funds received. The survey yielded letters from 250 scientists. The text below is an excerpt from Lederman's report and is followed by a postscript written by him expressly for this OTA report.[2]

* * *

. . . The responses paint a picture of an academic research community beset by flagging morale, diminishing expectations, and constricting horizons. . . .

> (There were) three incidents where we had to stand by while competitors from abroad moved forward on research based on our ideas. . . . The history of the past decade is one of continued harassment over money, lost opportunities due to inadequate support, and a stifling of imagination due to money worries. If U.S. scientists must continue to stand by and watch as our best ideas are carried forward by groups from abroad, our nation cannot hope to escape a rapid decline.
>
> —Professor of Physics,
> Massachusetts Institute of Technology

. . . Academic science has not arrived at its present state through a conscious decision by the Administration or Congress. No political leader has advocated starving science—indeed, most feel that they support it strongly. Presidents Reagan and Bush have both promised to double the size of the National Science Foundation's budget within five years, and Congress, almost every year, appropriates more for the National Institutes of Health than the Administration requests. . . .

However, recent growth has been insufficient to compensate for the effects of the long drought that preceded it. Thus, in the view of those in the laboratories, there has been a gradual year-by-year erosion in the availability of funding and in the health of academic science over nearly two decades. . . .

> I suspect that if I were twenty years younger I would not choose an academic research career. Even now I find myself considering other options. I'm tired of writing "excellent" proposals that aren't funded.
>
> —Professor of Chemistry,
> Duke University

. . . The (funding) problem is compounded . . . by a number of other factors that, taken together, further restrict the results that can be obtained from each research dollar. One factor is complexity—or what some observers have called "sophistication inflation." As our understanding of nature increases, the questions we need to answer become more complex. There is a corresponding increase in the sophistication (and cost) of the equipment needed to do research, both for small, "table top" experiments and large facilities such as telescopes and accelerators. . . . The cost of regulation is a second factor. In many fields, particularly in the life sciences, increased regulation absorbs significant funds and research time. . . . A third factor is institutional overhead. According to the National Science Foundation, indirect costs at universities (including administration, maintenance of buildings, utilities, etc.) have risen from 16 percent of the national academic R&D budget in 1966 to about 28 percent in 1986. . . . (and this) means that less money is available to the laboratory scientist for the direct costs of research. . . .

The problem is more serious than average grant size or proposal success rates (at the National Science Foundation and the National Institutes of Health), however. The letters reveal potentially important changes in the way scientists as individuals pursue their craft. As a consequence of the increasingly difficult search for funding, academic scientists are less willing to take chances on high risk areas with potentially big payoffs. Instead, they prefer to play it safe, sticking to research in which an end product is assured, or worse, working in fields that they believe are favored by funding agency officials. These scientists are also increasingly viewing their fellows as competitors, rather than colleagues, leading to an increasingly corrosive atmosphere. The manifestations of this attitude range from a reluctance to share new results with other scientists to public bickering about relative priorities in funding different fields.

> We are tending to do "safer" projects, avoiding the high risk, but high payoff projects. In the present climate we cannot afford to have experiments not work. . . . Undergraduates, graduate students and postdocs continually ask about the benefits of pursuing an academic career when funding is so tight.
>
> —Assistant Professor of Biology,
> Carnegie-Mellon University

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[1] *Science: The End of the Frontier?* a report from Leon M. Lederman, president-elect, to the Board of Directors of the American Association for the Advancement of Science (Washington, DC: American Association for the Advancement of Science, January 1991).

[2] OTA does not necessarily agree with the conclusions either in the report or the postscript.

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. . . .(In addition) respondents reported that they are cutting back on the number of students they are training, and that students now in the laboratories are opting out of research careers. . .

> While the current loss of productive groups is serious, even more disturbing is the negative influence the present difficulties are having on the next generation. On a recent visit to MIT I had an informal lunch with about twenty graduate students in organic chemistry and asked how many of them were going into academic science. One person raised his hand and he was returning to a small liberal arts college where he had been a student. This group agreed that their lack of interest in university level positions is their perception that the challenge of gaining funding is now dominant over the challenge of the science.
>
> —Professor of Chemistry,
> University of Illinois

What would it take to relieve the acute problems in academic research and restore U.S. science to its pre-1968 excellence? Let us consider this question independently of "practical" constraints dictated by current events. My analysis . . . indicates that we should be spending at least twice as much as we were in 1968 (in constant dollars) if we are to approach the conditions of (this era). Indications from NSF, NIH and DOE tend to confirm the pressure for a doubling of the current level of funding for academic science, which amounts to about $10 billion a year. This huge sum could, I believe, be effectively deployed in two or three fiscal years.

Beyond this, in future years, I would argue that the growth of four percent per year in the number of academic scientists and the complexity factor growth estimate of five percent per year imply that a sustained flourishing of academic research requires annual real growth of eight to ten percent. . . . Such an increment may sound substantial in our current climate, but as the economy responds, academic research would remain only a tiny fraction of total federal spending for many decades. Furthermore, even with such increases, it would be a decade or two before our level of nondefense research expenditure proportional to GNP would equal the 1989 levels of Japan or West Germany.

February 1991 Postscript

In his budget for FY 1992, the President requested significant increases for science, averaging 5-10 percent above inflation. In view of the fiscal constraints, scientists must stand in awe at the respect their work has earned. This is the eighth year of real increases initiated by the Administration and passed by Congress. Nevertheless, the AAAS inquiry has dramatically confirmed indications of serious troubles at the laboratory bench.

There are several reasons for believing that, in spite of these increases, the Nation is seriously underinvesting in research. One is the comparison with what our economic competitors are doing. Another is the comparison of our relative research capability today with what it was in the late 1960s.

International prizes (identifying when the work was done) as well as patents and a hard-to-quantify loss of scientific and technological self-confidence point in the same direction. The unprecedented stress within the scientific community described above is another indicator.

The crisis documented in the AAAS survey must be viewed as part of a larger pattern of national decisions. My analysis indicates that a continuation of the kind of investment we were making in the 1960s would have brought us today to somewhere near $30-40 billion for academic research. This is what motivated the "unrealistic" proposal for a doubling of the budget with subsequent 8-10 percent annual increases for at least a decade.

We are keenly aware that we have concentrated on only one important element of a problem that must include many other components, such as non-military R&D in industry and the national laboratories, and the overall scientific literacy of the work force. Research and education are so intimately entwined that they must be treated together. Only very briefly mentioned in the report are the human resources devoted to what economist Robert Reich calls "strategic brokers," those who translate R&D results into economic products. The record of U.S. investment in research and education, even given the increases, is one of decline relative to the GNP and relative to other industrialized societies. Whereas it is surely true that sums allocated by the Federal Government could always be spent more efficiently (especially in education), the problem is clearly underinvestment. Yet the primary asset of a modern industrial nation in the 21st century is its brainpower: a skilled, educated workforce.

The vision to recognize this as a salient feature of our times resides in many of our leaders. No doubt some such perception explains the favoring of science in tough times. However, the resources that are really demanded are far greater, as has been "unrealistically" proposed in the AAAS report. Nevertheless, if these human capital investments are judged in the context of a $5 trillion GNP or a $1.4 trillion Federal budget, it becomes clear that the issue isn't cost—it is a matter of choice. The choice is to treat the human resources of the Nation—an educated, capable work force—as the key to a successful society. If we choose wisely, and I let my imagination soar, the expenditure for academic scientific research will one day reach $50-100 billion (in 1991 dollars). With commensurate investment in education and infrastructure, we can restore not the world leadership we once enjoyed, but the position of the Nation as a dynamic and resourceful society, a leading participant in the new global economy of the 21st century. If we fail to see this long term issue, if we are dominated by our "third quarter" crises, if we hesitate because we have lost faith in the power of the human mind, our long term prospects will be dismal indeed.

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Medicare, and Medicaid), net interest on the Federal debt, and Federal spending on research.[17] While the deficit continues at record levels, the Omnibus Budget Reconciliation Act of 1990 will temper Federal spending, including possible modifications and further priority setting in expenditures for research.[18]

In addition, the scientific community has grown in size since the 1960s, reflecting a rising research economy that supported the pursuit of many spectacular opportunities. However, as more knowledge is gained, expenditures for cutting-edge research have also increased. These factors have combined to magnify the burdens on research performers and institutions, and on the Federal sponsors that fund them.[19] Many in the research system also wonder, as the uncertainty increases over enrollments by U.S. students in science, whether the next generation of scientists and engineers will sustain the research enterprise.[20] The pressures mount on public policy to decide which opportunities are most urgent, which agency programs to favor, and the rationale for supporting a diversity of fields, sectors, and research personnel. In the words of Yale Medical School Dean Leon Rosenberg:

> The scientific community is responsible in a major way for the paradoxes and dilemmas in which we find ourselves. . . . There are more opportunities than ever to ferret out the secrets of human biology and apply those secrets to the reduction of human suffering. The dilemma is that we must obtain more funding for the support of this effort in order to capitalize on those opportunities and improve the morale of the scientific community, while at the same time acknowledging that we have been generously supported for the past 40 years.[21]

This report explores the "paradoxes and dilemmas" of supporting U.S. science in the 1990s, while this chapter introduces the history of the Federal research system and current challenges that demand Federal policy attention.

Historical and Current Federal Roles in the Research System

The Federal research system has many participants. They include Congress, the Federal research agencies, the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), academic research institutions, Federal and industrial laboratories, the National Academy of Sciences complex, professional societies, think tanks, and others.[22] Together these components sponsor, perform, and guide the activity called "research."

Recognition of the role of the Federal Government in the support of research grew during the early parts of the 20th century, especially before and immediately after World War II. During the 1930s and 1940s, the Departments of Defense (DOD) and Agriculture (USDA), the Public Health Service (largely through the National Institutes of Health, NIH), and the Atomic Energy Commission (then, the Energy Research and Development Administration, and now the Department of Energy, DOE) collectively funded a diverse Federal research portfolio.[23] In the 1950s, the National Aeronautics and Space Administration (NASA) began to sponsor space exploration projects, and in the 1960s, it launched a celebrated and successful effort to safely land humans on the Moon and to gather data on the solar system. Federal research was supported and selected in partnership with the scientific community and with little constraint to adhere to formal agency missions.[24]

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[17] "Outlays by Category," *Government Executive*, vol. 22, September 1990, p. 44.

[18] See Jeffrey Mervis, "Science Budget: A Zero-Sum Game," *The Scientist*, vol. 4, No. 24, Dec. 10, 1990, pp. 1, 6; and David C. Morrison, "Pinching the Research Budget," *National Journal*, vol. 22, No. 49, Dec. 8, 1990, p. 2996.

[19] See William D. Carey, "R&D in the Federal Budget: 1976-1990," and Rodney W. Nichols, "Mae West at Olympus: Five Puzzles for R&D," both in *Science and Technology and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), pp. 43-51, 53-69.

[20] The gap between current rhetoric and current problems in science education as they relate to the Nation's research capability is examined in Iris Rotberg, "I Never Promised You First Place," *Phi Delta Kappan*, vol. 72, December 1990, pp. 296-303.

[21] Quoted in Dick Thompson, "The Growing Crisis in Medical Science," *Time*, Dec. 17, 1990, p. 21.

[22] Because universities perform the preponderance of basic and applied research and train most of the research work force, and because much of the data on research performance has been collected on academia, this report often focuses on academic research performers. However, when relevant, and especially where data are available, other performers are discussed.

[23] See Margaret W. Rossiter, "Science and Public Policy Since World War II," *Historical Writing on American Science: Perspectives and Prospects*, S.G. Kohlstedt and M.W. Rossiter (eds.) (Baltimore, MD: Johns Hopkins University Press, 1986), pp. 273-294; and Julius H. Comroe, Jr., *RetroSpectroScope: Insights Into Medical Discovery* (Menlo Park, CA: Von Gehr Press, 1977).

For many years, the core of the national effort in science was increasingly understood to reside in and be expressed through the National Science Foundation (NSF).[25] A 1965 National Academy of Sciences report, *Basic Research and National Goals*, went so far as to state that:

> . . . the National Science Foundation is viewed . . . as being responsible for . . . "intrinsic basic science," the motives for which are relatively remote from politically defined missions. Since this is a social overhead whose connection with specific applied objectives of the society is distant and undefined, it would seem . . . that allocation of resources to this activity would be even more difficult than the allocation to mission-related research.[26]

Since NSF primarily funded research in universities, science policy was generally equated with the provision of resources for research, principally through the university-based research system.

Although DOD, NASA, DOE, and USDA had significant basic and applied research budgets in the 1960s and 1970s, and NIH funding soared with the War on Cancer in the early 1970s, it was not until the 1980s that infusions in defense research and development (R&D) and the debates over the importance of federally sponsored applied research once again highlighted the pluralistic Federal role.[27] "The fragmented, mission-oriented structure that emerged after World War II went a long way toward realizing Vannevar Bush's vision of a Federal system for the support of science and engineering. In large measure, it was responsible for the emergence of the great American research universities and the 'golden age' of science."[28] Today, research is understood to be an activity pursued in many agencies of the Federal Government and sectors of the U.S. economy.[29]

The wisdom of the compact between science and the Federal Government has been demonstrated repeatedly in the last half of the 20th century. As more and more has been explicitly demanded of scientific and technological institutions in U.S.

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[24] See U.S. Congress, House Committee on Science, Space, and Technology, Task Force on Science Policy, *A History of Science Policy in the United States, 1940-1985*, 99th Cong. (Washington, DC: U.S. Government Printing Office, 1986), especially pp. 15-40; also see Alan T. Waterman, "Basic Research in the United States," *Symposium on Basic Research*, Dael Wolfle (ed.) (Washington, DC: American Association for the Advancement of Science, 1959), pp. 17-40. The celebrated Mansfield amendment, passed as part of the fiscal year 1970 Military Authorization Act (Public Law 91-121), prohibited military funding of research that lacked a direct or apparent relationship to a specific military function. Through subsequent modification, the Mansfield amendment moved the Department of Defense toward the support of more short-term applied research in universities. For a discussion, see Genevieve J. Knezo, "Defense Basic Research Priorities: Funding and Policy Issues," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Oct. 24, 1990), pp. 5-9.

[25] While the Bush Report and the Steelman Report (introduced in ch. 1) were both effusive in their praise of the social benefits emanating from scientific advance and the underlying rationale for the Federal support of science, each took a different approach to the administration of a national science foundation. OTA points out that ". . . the Steelman report regarded science as a special interest. Although large-scale government support for science was a new phenomenon, science was not considered to be sufficiently different from other policy areas to warrant any special political relationships." Bush supporters were ". . . convinced that science was distinct from other types of government programs, that it must be free from political control, and that, to be successful, scientists should be able to direct their own affairs. . . . Scientists, . . . through advisory groups and a system of review by scientific peers, would decide how research should be conducted and would influence the research agenda." See U.S. Congress, Office of Technology Assessment, *The Regulatory Environment for Science*, OTA-TM-SET-34 (Springfield, VA: National Technical Information Service, February 1986), pp. 15-16.

[26] George B. Kistiakowsky, "Summary," in National Academy of Sciences, Committee on Science and Public Policy, *Basic Research and National Goals*, A Report to the Committee on Science and Astronautics, U.S. House of Representatives (Washington, DC: March 1965), p. 11. This collection of essays evolved, in the words of Committee Chairman George P. Miller, into ". . . the production of a comprehensive study designed to throw into bold relief some of the more serious phases of policy which Government must consider in its decisions to support or otherwise foster research in America." (p. v).

[27] From the researcher's perspective, multiple sources of Federal support provide funding flexibility, i.e., choice among agencies. From a Federal perspective, flexibility allows choice among alternative research initiatives and performers. New programs can be started or old ones refocused.

[28] Joseph G. Morone, "Federal R&D Structure: The Need for Change," *The Bridge*, vol. 19, fall 1989, pp. 3-13. For a discussion of the "university research economy," see Roger L. Geiger, "The American University and Research," in Government-University-Industry Research Roundtable, *The Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives*, report of a symposium (Washington, DC: National Academy Press, March 1990), pp. 15-35.

[29] The importance of nonprofit foundations and the private sector in supporting, defining, and utilizing basic research is also indisputable (though the extent of their participation differs greatly by field, industry, and measures of contribution). See National Science Foundation, op. cit., footnote 11.

society, the social contract has changed.[30] A new relationship may be evolving, but the trusteeship remains intact.[31] Today, with the expectation of sustained Federal support of science, concern has shifted to "how much growth" and "how to manage expansion." With acute and widespread awareness of the dependency of research institutions on Federal support, money has become the lightning rod of debates over science and other institutional domains. While this is apparent to most decisionmakers, equally important but less visible is the issue of the organization for making policy choices, i.e., how to distribute whatever monies are allocated for research.

Differing conceptions of urgency, time-scale, and level of investment feed tensions within the scientific community as Federal priorities change. In a dynamic, pluralistic system, discontinuities in funding can be expected. The Federal Government is accused of supporting faddish research on the one hand, and of sluggishness in responding to new research opportunities on the other. What is often seen as a choice between big science and little science, or between high-energy physics and molecular genetics, is often more apparent than real. Overall funding decisions are often shaped more by funding allocations between research and other national objectives.[32] As symbolized in the debates over the Superconducting Super Collider and the Human Genome Project, there is a sense of congressional urgency, frustration, and ambivalence over research goals.

While representative democracy ultimately invests the power of decisionmaking in elected officials of the Federal Government (who judge political and national needs), these decisions are tempered by expert advice. Such judgments have consequences for decisionmaking and accountability, especially at the research agencies.[33] More than the other branches of government, Congress—the representative of the public interest—is at the nexus of the trusteeship for research. Congress plays an increasingly active role, both in determining the Federal research budget and in stewarding the Federal research system in directions that serve the public good (see chapter 3).

Prospects for the 1990s

Science and engineering are increasingly vital parts of the Nation's culture; research contributes in many ways to the technological and economic base. Since the post-Sputnik era, both the capacity to perform research and the demand for funds to sustain scientific progress have grown. As the research enterprise moves into the 1990s, the Federal research system will experience changing funding patterns and various pressures from both outside and within the scientific community. How, in the face of changing funds and goals, can Congress ensure that the research system satisfies national needs, while retaining the diversity, flexibility, and creativity that have characterized U.S. contributions to scientific knowledge and its payoffs? Four challenges are clear.

First, new methods for setting priorities in research funding will be required. Looking across fields and at objectives that build on, but are not limited to, scientific merit is the responsibility of OSTP, OMB, the research agencies, and the scientific community, as well as Congress. Each may weigh funding criteria differently, but each has a role in preparing the enterprise for tomorrow's research opportunities as well as today's.

Concern over the amount and distribution of Federal research funding is voiced increasingly throughout Congress. As one former member put it:

> At present we have no well-defined process . . . for systematically evaluating the balance of the overall Federal investment in research and develop-

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[30] For commentary on how 40 years of Federal funding policy strayed from the letter, and perhaps even the spirit, of Vannevar Bush's vision of a centralized system, see Deborah Shapley and Rustum Roy, *Lost at the Frontier* (Philadelphia, PA: ISI Press, 1985). The House Committee's Science Policy Task Force concurred with this appraisal in 1986, observing that: "The National Science Foundation, originally conceived as a central coordinating body, was left with a restricted jurisdiction over unclassified, basic research." House Committee on Science and Technology, op. cit., footnote 24. As Morone, op. cit., footnote 28, p. 4, puts it: "In effect, Bush called for a Department of Science, which would fund research as well as education, natural sciences as well as life sciences, and mission-oriented research as well as general, or 'pure,' science."

[31] Kenneth Prewitt, "The Public and Science Policy," *Science, Technology, & Human Values*, vol. 7, No. 39, spring 1982, pp. 5-14.

[32] For a discussion, see Genevieve J. Knezo and Richard E. Rowberg, "Big and Little Science," *CRS Review*, February 1988, pp. 6-8; and "Money for the Boffins," *The Economist*, vol. 318, Feb. 16, 1991, pp. 15-16.

[33] Three OTA contractor reports, featured later in this report, provide data on the rhetoric of accountability used by various participants in the Federal research system. But see Office of Technology Assessment, op. cit., footnote 25. On the role of the media in promoting accountability, see Marcel C. LaFollette, "Scientists and the Media: In Search of a Healthier Symbiosis," *The Scientist*, vol. 4, No. 14, July 9, 1990, pp. 13-15.

> ment and in the variety of fields that we try to serve. The R&D budgets of the different Federal agencies are evaluated separately and largely independently, both within the executive branch and certainly here in the House and Senate. . . . Of particular interest are the criteria for evaluating competing research development projects in different fields and the organizational arrangements for helping us to do a better job of allocating scarce resources.[34]

Since the support of science and engineering research is vital for the future of the United States, the Federal Government attempts to maintain a strong "science base," i.e., research across a wide range of science and engineering fields.[35] To the extent that specific areas, problems, and projects may be singled out for enhanced funding, debate within the scientific community centers on the adverse impacts of funding large new initiatives, or "megaprojects," on the science base. The criteria and information to inform priority setting are thus paramount issues, as decisions must be made between competing goals.[36]

A second challenge is that, because demands for research funds are likely to continue to outpace funding in most parts of the research budget, strategies for coping—devised by sponsors and performers alike—will be needed. Congress is especially concerned about the question of costs, because the Federal Government supports research expenditures (e.g., salaries, indirect costs, equipment, and facilities) that have increased over the general rate of inflation. In addition, more researchers are performing federally funded research and, in the aggregate, are spending more across-the-board on their research projects.[37]

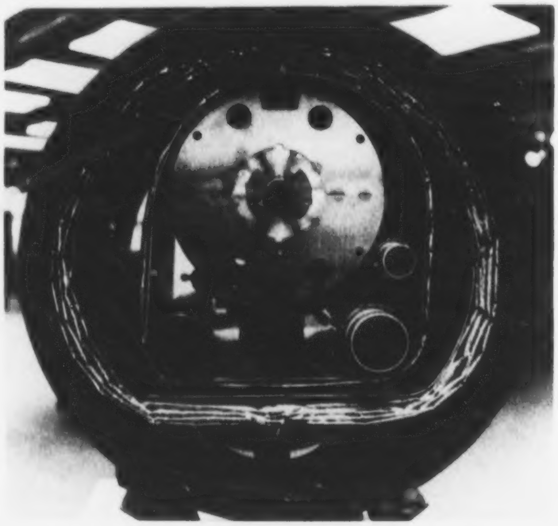

Photo credit: U.S. Department of Energy

This is a cross section of cable destined for the Superconducting Super Collider. Capital expenditures, especially for equipment, are an integral part of most megaprojects.

Recently, the Federal Government has experimented with ways to cope with the rising demands of research, i.e., the expectations that spending will increase in the performance of research. First, Congress imposed salary caps on NIH- and NSF-funded research grants. In fiscal year 1991, legislation relaxed these constrictions. Second, Congress and USDA recently placed a ceiling on the proportion of indirect costs allowable on research grants. This experiment has yet to be fully implemented, but it is expected that universities will attempt to recover their costs from the Federal Government by charging more items to direct costs that were formerly part of indirect costs.[38]

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[34] Doug Walgren, Chairman of the House Subcommittee on Science, Research, and Technology, in U.S. Congress, House Committee on Science, Space, and Technology, *The Hearings on Adequacy, Direction, and Priorities for the American Science and Technology Effort*, 101st Cong., Feb. 28-Mar. 1, 1989 (Washington, DC: U.S. Government Printing Office, 1989), pp. 1-2.

[35] For example, see David Baltimore, "The Worsening Climate for Biological Research," *Technology Review*, vol. 92, No. 4, May-June 1989, p. 22.

[36] At the agency level, tradeoffs are made routinely within research programs, and "peer review" informs the project choice of many programs, making them accountable to specialized research communities. When criteria in addition to scientific merit are included in peer reviews, however, selection mechanisms can come under duress. See Margaret Jane Wyszomirski, "The Art and Politics of Peer Review," *Vantage Point*, spring 1990, pp. 12-13. For recent appraisals of selection mechanisms and agency accountability for them, see U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, *Research Project Selection*, vol. 17, hearings, 99th Cong., Apr. 8-10, 1986 (Washington, DC: U.S. Government Printing Office, 1986); and National Science Foundation, Office of the Inspector General, *Semiannual Report to Congress*, No. 2, Oct. 1, 1989-Mar. 31, 1990 (Washington, DC: March 1990).

[37] Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington, DC: National Academy Press, October 1989), p. 2-32. More qualitative information is needed to understand the contexts of research performance and to interpret the quantitative estimates of time and expenditures reported in various National Science Foundation surveys. For example, see National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1990* (Washington, DC: September 1990).

Third, addressing the changing demands on the educational pipeline (K-12 through graduate study) for science and engineering will be vital for maintaining strength in the performance of research. Through the direct support of graduate students and the indirect support of research institutions, the Federal Government is pivotal in the creation of a robust research work force. OTA has documented the initiatives needed to maintain the readiness of the educational pipeline. Recruitment and retention programs can respond to changing demands for researchers and enhance preparation for diverse career opportunities for graduates with science and engineering Ph.D.s.[39]

Human resources are the principal component of the research system. Increasing participation in research by those groups chronically underrepresented in science and engineering (women, ethnic/racial minorities, and the physically disabled) and those acutely affected by resource constraints (e.g., young investigators, see box 2-E) is a challenge to the goal of enlarging capacity in the Federal research system. The Nation (not just science and engineering) gains from the flow of new Ph.D.s into this work force. The character of the flow (not just its intensity) will determine the robustness of the research system in the 1990s.

Finally, filling gaps and reducing uncertainties in policy-relevant information is essential for better informed decisionmaking. NSF is defined as *the* Federal agency ". . . to make comprehensive studies and recommendations regarding the Nation's scientific research effort and its resources for scientific activities."[40] Empirical knowledge about the Federal research system has grown immensely, yet each of the three issue areas outlined above suffers from a lack of some appropriate data on which to base Federal policy.

Photo credit: U.S. Department of Agriculture

A researcher studies the growth of a plant. Increasing the participation of traditionally underrepresented groups in science and engineering will continue to be a focus in federally funded research.

New research indicators are needed as a means of monitoring change in the Federal research system.[41] OTA has also found (see chapter 8) that the evaluation of research projects would add to the investment decisions of policymakers and program

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[38] For example, see Colleen Cordes, "Universities Fear That U.S. Will Limit Payments for Overhead Costs Incurred by Researchers," *The Chronicle of Higher Education*, vol. 37, No. 12, Nov. 21, 1990, pp. A19, A21. For a university perspective, see Association of American Universities, *Indirect Costs Associated With Federal Support of Research on University Campuses: Some Suggestions for Change* (Washington, DC: December 1988).

[39] See three reports by U.S. Congress, Office of Technology Assessment: *Educating Scientists and Engineeers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988); *Elementary and Secondary Education for Science and Engineering*, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988); and *Higher Education for Science and Engineering*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

[40] The National Science Foundation was thus named the agency data liaison and monitor. For the scope of these responsibilities, see especially sections 2-3 and 5-8 of Executive Order 10521, reproduced in J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945-57* (Washington, DC: National Science Foundation, 1982), app. 1, quote from p. 353.

[41] For example, see Carlos Kruytbosch and Lawrence Burton, "The Search for Impact Indicators," *Knowledge: Creation, Diffusion, Utilization*, vol. 9, December 1987, pp. 168-172.

Box 2-E—The Perils of Being a Young Investigator

"The next generation." "The seed corn." "The future of scientific research." These are some of the words used to describe young investigators. Current commentary on the funding of research grants, especially in biomedicine and by the National Institutes of Health (NIH), centers on the fate of young investigators.[1] This commentary underscores the unity of training and research, yet suggests the strain experienced by a growing segment of the research work force.

Many see the problems of young investigators as a natural adjustment of the research labor market to greater competition in funding or to changes in the structure of research teams. In the words of Rockefeller University President David Baltimore: "How much growth in biomedical research personnel is needed and how much is healthy?"[2] Others see the plight of young investigators as stemming from problems in funding allocation mechanisms. Recognizing that the young investigator with little or no track record is at a disadvantage in head-to-head competition with senior investigators for Federal research funds, both NIH and the National Science Foundation (NSF) have established mechanisms that narrow the pool of eligibles. NIH's First Independent Research Support and Transition (FIRST) awards grant 5 years of support, not to exceed a total of $350,000, to successful first-time applicants to NIH.[3] Begun in 1987, recipients of FIRST awards (R-29s) have indeed fared better than other young investigators in competing for traditional individual-investigator (RO1) funds. In fiscal year 1988, one-half of the R29 awardees were under 36 years of age, compared to 14 percent of RO1 recipients, and 23 percent of the young investigators were female compared to the 14 percent of traditional NIH grant recipients.[4] Perhaps the best news for those who monitor award trends is that once young investigators get an NIH grant, they win renewals as often as senior investigators.[5]

At NSF, the much-heralded (now 7-year-old) Presidential Young Investigator (PYI) program awards 5 years of funding.[6] PYIs are augmented in two directorates by Research Initiation Awards. These provide up to $100,000 for 2 years, including an institutional matching incentive to help defray equipment costs. In 1989, 726 applications were received; 17 percent were funded. This constituted mild relief from the slim success rates, roughly one in five, that first-time applicants have experienced since 1984 throughout most NSF programs. (More seasoned investigators have succeeded during that period at a rate of one in three.)[7]

New PhDs "itch," in the words of one, to establish their own laboratory, attract graduate students, and produce experimental results. The goal is to replicate the career pattern of one's mentor. But, can every young investigator become a PI? This will bring more proposals, more competition, more demands for research funds. A young investigator with an excellent NIH priority score for her proposal but no money says: "When we slam up against this problem, we have self-confidence to say 'this is unjust,' not 'I am unworthy.' In a way, it takes an egoist to persevere."[8]

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[1] Their perils were the major subtext, for example, at the National Academy of Sciences/Institute of Medicine, "Forum on Supporting Biomedical Research: Near Term Problems and Options for Action," Washington, DC, June 27, 1990. In addition, the National Research Council's Commission on Life Sciences is studying the funding of young investigators. A report is due in fall 1991. See "Scientists Explore Ways To Help Young Researchers," *NewsReport of the National Research Council*, vol. 40, August-September 1990, pp. 6-8.

[2] Quoted in "NIH Crowd Seeks New Ways Out of Money Crunch," *Science & Government Report*, vol. 20, No. 13, Aug. 1, 1990, p. 2.

[3] See Joe Palca, "NSF, NIH Apply Band-Aids," *Science*, vol. 249, July 27, 1990, p. 352.

[4] National Institutes of Health, Division of Research Grants, "Briefing on NIH FIRST Activity," spring 1989, pp. 6, 15, 18.

[5] Palca, op. cit., footnote 3.

[6] This program awards about 200 grants per year with the expectation that during the 5-year period industry funding will be secured to solidify the investigator's research program and its impact. Even with industrial funding, however, the researcher is likely to apply for regular grant support. A National Science Foundation task force has recently recommended cutting the number of Presidential Young Investigator awarded by one-half, increasing the award amount and dropping the matching fund requirement, as well as amending the application process to include a full-blown proposal instead of nominating and endorsing letters from mentors and other senior investigators. See Pamela Zurer, "NSF Young Investigator Program May Be Slashed," *Chemical & Engineering News*, vol. 68, No. 50, Dec. 10, 1990, p. 7; and "Presidential Young Investigators" letter, *Chemical & Engineering News*, vol. 68, No. 50, Dec. 10, 1990, p. 5.

[7] Joe Palca, "Young Investigators at Risk," *Science*, vol. 249, July 27, 1990, p. 353; the National Science Foundation also reports "new investigator awards," i.e., awards to applicants not funded by NSF in the previous 5 fiscal years. Since 1984, 20 to 25 percent of total awards were made to new investigators. See *Manpower Comments*, vol. 27, No. 5, June 1990, p. 31.

[8] Palca, op. cit., footnote 7. A junior faculty member at the Salk Institute adds: "I worry because the NIH can't be trusted. The tighter the funding at NIH, the greater the chance your grant will be killed by bad luck—not because it isn't good science." Ann Gibbons, "The Salk Institute at a Crossroads," *Science*, vol. 249, July 27, 1990, p. 361.

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Box 2-E—The Perils of Being a Young Investigator—Continued

Another tack is to be (reluctantly) pragmatic, ". . . buttering up senior researchers and NIH review panel members who could help their chances of getting funded. . . . When good science could get you a grant, you didn't need to do it. Now you have to, and that's turning many people into cynics."[9] Is the next generation to be the ones who feel deceived when the system does not work for them the way it was "supposed" to? This is a question of expectations. A recent survey of young physics faculty at all 175 physics Ph.D.-granting universities in the United States (conducted by the American Physical Society) adds another perspective to gauging the plight of the young investigator.[10] In 1990, 70 percent of the young physics faculty reported that research funding is inadequate, whereas in 1977 less than 25 percent responded similarly. Of the 1990 young Ph.D. faculty who submitted "start-up" (i.e., their first) proposals, condensed matter physicists submitted the largest average number of proposals (over five), and experienced the lowest success rates (25 percent). All other subfields had success rates from 38 to 55 percent.[11]

The report concludes that ". . . . there has been a major change for the worse in the research climate." For condensed matter physicists, most of whom consider NSF the dominant source of support, this may be true. But the perceptions do not generalize across all subfields. Indeed, both 1977 and 1990 young physics faculty overwhelmingly "would recommend physics" and would choose to pursue a career in physics again. In addition, twice the proportion of 1977 young faculty claimed that the "job market was worse than expected" than reported by the 1990 young faculty (61 percent to 31 percent).[12]

The merits of additional support to young investigators cannot be overstated. How this is to be achieved poses formidable challenges to research agencies and program managers, as well as to the scientific community. All contribute to the expectations and the standards for measuring the research performance of new Ph.D.s. For those young investigators who embark on academic research careers, the prospect of a FIRST, PYI, or Research Initiation award is vital if they are to become senior researchers. NIH and NSF face choices, too, in shaping researchers' expectations. These choices might include:

- limiting the amount of Federal funding that goes to one principal investigator, taking into account all sources of Federal research funds and cost differences among fields;
- addressing policies at some universities that prohibit nonfaculty personnel from applying for Federal research funds as principal investigators, and encouraging these universities to lift such bans;
- requiring the sharing of doctoral students and instrumentation; and
- encouraging universities to restrict the number of refereed publications considered for promotion, tenure, and other awards (to decrease the amounts of Federal funding required to publish longer lists of research papers).[13]

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[9] Palca, op. cit., footnote 7, pp. 352-353.

[10] The questionnaire was circulated to 939 physicists who earned a Ph.D. degree in 1980 or later and then received academic appointments. The response rate was 71 percent. See Roman Czujko et al., *Their Most Productive Years*, Report on the 1990 Survey of Young Physics Faculty (Washington, DC: American Physical Society, 1991) (reprinted in *Physics Today*, February 1991, pp. 37-42).

[11] Condensed matter physicists represented the largest subfield (one-third of the total respondents) in the 1990 sample. Ibid., table 3.

[12] Ibid., table 5.

[13] For discussion of these and other ideas, see Institute of Medicine, *Funding Health Sciences Research: A Strategy To Restore Balance* (Washington, DC: National Academy Press, November 1990). For insight into the contentiousness that greeted the Institute of Medicine report, see Peter G. Gosselin, "A Clash of Scientific Titans: Key Groups Battle Over Funds for Medical Projects," *The Washington Post*, Health section, Dec. 18/25, 1990, p. 6.

managers and would further serve to keep agencies alert to problems in the process of research performance.[42] Filling information gaps in the Federal support structure and creating policy-useful indicators and evaluations could assist policy formulation by both the legislative and executive branches and

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[42] Trend data are desirable because they reveal the early signals of flagging or surging health in one area or another. Because what is being measured is changing over time, such trends are open to interpretation. In short, interpretation must keep apace of growing sophistication in measurement. This and not the data alone becomes information for decisionmaking. See, for example, Ciba Foundation, *The Evaluation of Scientific Research* (New York, NY: John Wiley & Sons, 1989); Computer Horizons, Inc., "An Assessment of the Factors Affecting Critical Cancer Research Findings," executive summary, NIH Evaluation Project No. 83-304, Sept. 30, 1987; and U.S. Congress, Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Returns?* OTA-SET-TM-36 (Washington, DC: U.S. Government Printing Office, April 1986).

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help to inform decisionmakers about the effects of a changing research economy on research priorities, expenditures, and performers. Information, however, is not cost-free. Additional funding both for agency data collection and analysis, and extramural "research on research," may be a necessary investment in the Federal research system of the 1990s.

In the chapters that follow, OTA delineates the participants and their roles in the research system. After introducing this decentralized system—how the executive and legislative branches negotiate national goals and the Federal budget, and how the agencies determine the allocation of research funds—OTA assesses the challenges to managing federally funded research.

CHAPTER 3

The Federal Research System: The Executive and Legislative Branches

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CHAPTER 3

The Federal Research System: The Executive and Legislative Branches

> *In the final analysis, after science and technology decisions have been subject to the judgment of conflicting objectives, . . . they are then subject to the reality of the Federal budget process. First research and development programs must compete with other Federal programs for the availability of limited Federal dollars . . . for there will always be more programs and projects than there will be funds to implement them. Thus another set of choices in how to allocate the funds to gain the greatest benefits must be faced.*
>
> Don Fuqua[1]

Introduction

It is often said that the best scientists not only know how to solve problems, but how to pick them. Choosing where to put valuable time and resources is central to the success of any scientist, laboratory, or university. The same is true for the Federal Government.

Decisionmaking occurs on many levels within the Federal research system. The most macroscopic level for research decisionmaking concerns a spectrum of general research problems such as space exploration, aging, or AIDS (acquired immunodeficiency syndrome). The President and Congress are ultimately responsible for decisions made at this level. At mid-levels, the focus shifts to fields such as astrophysics, virology, or artificial intelligence. Most often Federal agencies and specific congressional committees take the lead in these decisions. Priorities within a single field of science or technology usually involve specific government programs and congressional subcommittees. And, finally, at the most microscopic level, the focus is on areas of research specialization and often involves specific processes of funding allocation.[2]

A focus of this report is the tremendous diversity within the Federal Government in the selection of priorities for research. Every Federal agency and congressional committee seems to do it differently.[3] If the government is to respond to changing fiscal conditions, many choices within the organization and management of the research budgets must be made.

This chapter discusses the highest level of decisionmakers—the President, the executive branch, and Congress. (Chapter 4 introduces the Federal agencies and other participating bodies.) Although in this discussion the executive and legislative branches are treated separately, there is important interaction between them, both formally at congressional hearings and executive branch briefings and informally among staff.

The Executive Branch

When President Bush awarded the National Medal of Science and the National Medal of Technology to 30 scientists and engineers in November 1990, he remarked: "More and more our Nation depends on basic, scientific research to spur economic growth, longer and healthier lives, a more secure world and indeed a safer environment."[4]

Traditionally, Presidents have been very supportive of science and engineering, or what is categorically known as research and development (R&D). However:

> Every administration refers each year to its "R&D budget," which is described in various documents—most notably, Special Analysis J, produced by the Office of Management and Budget. In actuality, there is no Federal R&D budget, if by

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[1] Don Fuqua, "Science Policy: The Evolution of Anticipation," *Technology in Society*, vol. 2, 1980, p. 372.

[2] For overviews, see Bruce L.R. Smith, *American Science Policy Since World War II* (Washington, DC: The Brookings Institution, 1990); and David Dickson, *The New Politics of Science* (New York, NY: Pantheon, 1984).

[3] And viewed in a cross-national framework, the U.S. research system is distinctive. See app. D for a discussion of priority setting in other countries.

[4] Quoted in "National Medals Are Pinned on 30 Scientists," *The Washington Post*, Nov. 15, 1990, p. A23.

Photo credit: Michael Jenkins

The House Committee on Agriculture, which has jurisdiction over the Department of Agriculture and its research programs, votes.

''budget'' is meant a plan for matching priorities with spending. What each administration presents to the public is an after-the-fact compilation of the R&D spending plans of the individual mission agencies and NSF, plans that were developed through a complex and fragmented sequence of local interactions among individual groups with the agencies, the White House Office of Science and Technology Policy, and a slew of congressional committees.[5]

The most consistent indicator of Presidential priorities over the last 30 years has been the Presidential Budget Message, presented to Congress every year, which accompanies the Presidential budget. A review of these documents, extending back to the Kennedy Administration, gives an interpretation of Presidential direction, at least rhetorically, of the Federal research system.[6]

During the 1960s, the mastery of space and space science, as symbolized by a manned lunar landing, was a central mission. Competition with the Soviets both in research and economically was the center of the debates. Domestic research needs received increasing emphasis from 1964 through 1968, linked to the programs and aspirations of the Great Society, but tempered by economic constraints stemming from increasing involvement in Vietnam. Pollution also became a major item of concern from 1964 onward. Specific research emphases included: National Aeronautics and Space Administration

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[5] Joseph G. Morone, ''Federal R&D Structure: The Need for Change,'' *The Bridge*, vol. 19, fall 1989, p. 5. Special Analysis J was discontinued in 1990, but is discussed below.

[6] The following is based on Mark Pollack, ''Basic Research Goals: Perceptions of Key Political Figures,'' OTA contractor report, June 1990. Available through the National Technical Information Service, see app. F. Readers will note below the lumping of ''R'' and ''D,'' as well as the lack of distinction between ''basic'' and ''applied'' research. The macro view seeks the big picture, e.g., R&D relative to transportation, veterans' affairs, and other national needs. Refinements come in later chapters.

(NASA) pursuit of manned flight, planetary probes, and scientific satellites; National Science Foundation (NSF) support of facilities at universities and colleges to strengthen science education; health research, including the prevention of cancer, heart disease, strokes, mental illness, mental retardation, and environmental health problems; environmental research, including resource conservation and development, oceanographic studies, and water and air pollution abatement; transportation research; and defense research.

During the 1970s, as space flight and research were scaled back, energy research issues became increasingly prominent, emphasizing the development of energy alternatives and the improvement of existing ones. These issues were linked to growing concern about dependence on foreign oil, and also to environmental concerns of pollution and conservation of natural resources. Specific energy research programs were emphasized by President Nixon and others, including fusion power and geothermal and solar energy. President Carter stressed conservation and alternative energy sources and advancement in nuclear power technology. Defense research was consistently supported, and preservation of national economic preeminence remained a strong goal on all fronts.[7]

During the 1980s, economic recovery, competitiveness, and leadership were the rhetorical focal points of discussions of the goals and justifications for research. Specific attention to the category of "basic research," begun in Presidential addresses during 1978, was linked to goals of economic, military, and technological leadership (although these goals were not necessarily reflected in the distribution of research funds, e.g., defense basic research funding did not increase markedly in the 1980s). In the Presidential messages of 1982 to 1986, the shift of Federal aid to scientific research and away from application and development became explicit. Cuts in applied energy research and agricultural sciences were made, while basic energy, defense, and biomedical research were augmented. In the late 1980s, as in the early 1960s, big science research projects were featured on the Presidential agenda. The Space Station, the Strategic Defense Initiative, AIDS, the Human Genome Project, and the Superconducting Super Collider (SSC) all figured prominently.

Photo credit: Jamie Notter, OTA staff

The President can be a major architect of the research system, and some Presidents have shown more interest in research and development issues than others.

American Presidents of the last three decades have paid heed to maintaining the science base—the broad spectrum of researchers and research supported by the Federal Government—but have also felt the need to concentrate resources toward achieving stated research goals. During the 1960s, when research budgets were increasing rapidly, the President could add new objectives to the system while maintaining other research programs. Now, Presidents must make more choices in fiscal allocation. For example, President Reagan distinguished between basic and applied research, favoring the former with budget increases and decreasing the latter in specific areas such as energy. (Under the Bush Administration, this distinction faded and several applied energy projects have been pursued.)

However, Presidents have generally been less involved in decisions about research policy than in areas such as economic, space, or defense policy (with the possible exception of decisions about particle accelerators). Until recently, Presidents often viewed research as within the purview of specific agencies, intertwined with the development of technologies and the procurement of certain goods or services, but rarely a policy objective per se. To keep abreast of research issues, the President relies on many groups including the Office of the Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB).

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[7] David Birdsell and Herbert Simons, "Basic Research Goals: A Comparison of Political Ideologies," OTA contractor report, June 1990. Available through the National Technical Information Service, see app. F.

The Science Advisor

Science Advisors most often have impeccable technical credentials and extensive experience within the scientific community[8] (see figure 3-1). President Eisenhower appointed James Killian the first titled Science Advisor in 1958. At present, D. Allan Bromley holds that position. He is typical of past science advisors: physicists with outstanding research records and a history of participating in government advisory committees on science and technology.[9] Advisors over the last 30 years have come from industry and university settings.

One criticism of Science Advisors has been that they favor the physical sciences, while Presidential goals have included life and social science objectives as well.[10] Another criticism of the position is that, while acting as the representative of the President, advisors are also seen as allies of the science community from which they were recruited, expected to give advice on all scientific matters as a "scientist." This dual role can be difficult. Some advisors, notably Keyworth and Graham in the Reagan Administration, were regarded as outsiders by the scientific community. They were less trusted and seen more as voices articulating the President's ideological agenda.

Since the Office of Science and Technology Policy Act in 1976, the Science Advisor has also been the director of OSTP.[11] OSTP was created by Congress to strengthen the role of the Science Advisor by creating a position that was parallel to the Director of OMB and the Chairman of the Council of Economic Advisors.[12] OSTP currently includes a small staff—less than 75—with a portion of the personnel detailed from various Federal agencies. With the confirmation of a new advisor (which usually coincides with the beginning of a Presidential administration), a new OSTP staff is assembled. Consequently, few senior OSTP staff will serve in their positions for longer than 4 to 5 years. However, many have extensive experience within the executive branch, Congress, or the scientific community. While this staff turnover requires that the Science Advisor and OSTP "start from scratch" and provides limited institutional memory, it also allows OSTP to construct a new agenda with each advisor.

In addition to providing a resource for scientific and technical information for the President, the responsibilities of OSTP include coordination of R&D activities throughout the agencies. The Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), under the chairmanship of Science Advisor Bromley, provides a forum for coordination.[13] Bromley has paid special attention to FCCSET during his tenure, increasing the participation of senior agency personnel. In 1989, there were nine active FCCSET committees.[14]

The Science Advisor also chairs the President's Council of Advisors in Science and Technology (PCAST), which provides independent expert advice to the President. PCAST was created in 1989 in the image of the President's Science Advisory

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[8] William Golden, *Science and Technology Advice to the President, Congress, and Judiciary* (New York, NY: Pergamon Press, 1988).

[9] James Killian was a notable exception. He was trained as a humanist who rose through the ranks at the Massachusetts Institute of Technology as an administrator. He was accepted into the scientific community and treated as an equal member. Harvey Brooks, Harvard University, personal communication, February 1991.

[10] In an interview soon after his appointment, Bromley admitted the overrepresentation of physical scientists on such bodies as the President's Science Advisory Committee, pointing out that ". . . the life sciences must be brought in more strongly than they are now." See Jeffrey Mervis, "New Science Advisor Sees Strong Ties to Bush, Public Support as Keys to Job," *The Scientist*, vol. 3, No. 11, May 29, 1989, p. 3.

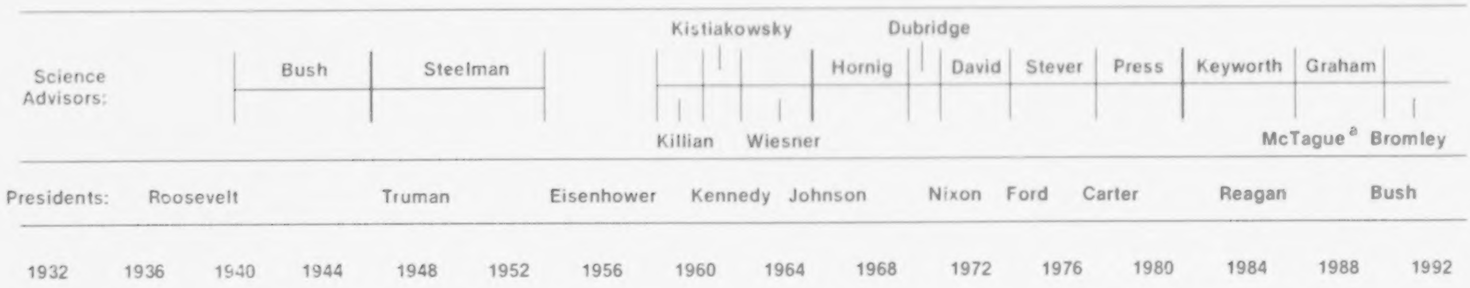
[11] The forerunner of the Office of Science and Technology Policy was the Office of Science and Technology (OST). The position of OST director was created by President Kennedy in 1961.

[12] Richard C. Atkinson, "Science Advice at the Cabinet Level," in Golden, op. cit., footnote 8, p. 12.

[13] For a history of the Federal Coordinating Council for Science, Engineering, and Technology, see Congressional Research Service, *Interagency Coordination of Federal Scientific Research and Development: The Federal Council for Science and Technology*, Report to the Subcommittee on Domestic and International Scientific Planning and Analysis, Committee on Science and Technology, U.S. House of Representatives, 94th Cong. (Washington, DC: U.S. Government Printing Office, July 1976).

[14] Genevieve J. Knezo, "White House Office of Science and Technology Policy: An Analysis," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Nov. 20, 1989), pp. 61-62.

Figure 3-1—Science Advisors to the President, 1932-90



[a] McTague was acting Science Advisor between Keyworth and Graham.

SOURCE: Adapted from William G. Wells, School of Government and Business Administration, George Washington University, "Science Advice and the Presidency, 1933-76," unpublished dissertation, 1977, p. 18.

Committee (PSAC), which had been disbanded by President Nixon in 1973.[15] (Although the authorization to constitute a new PSAC was included in the 1976 legislation which created OSTP, no action was taken until 13 years later.) Members of PCAST, appointed by the President, are distinguished leaders in science and engineering from industry, philanthropy, and academia. Although PCAST can be asked to comment on specific scientific and technological matters, it can also offer opinions on other issues and solicit its own outside analysis. (PCAST has only been in operation for a little over a year, so it is difficult to determine the role that it may play in the 1990s.[16])

PCAST, OSTP, and the Science Advisor are advisory to the President. As such, they have not been given much power. As a former staff member in the George Keyworth-led OSTP writes:

> The position of the President's Science Advisor (and director of OSTP) is strictly a staff function, with no line authority and no control over budgets. The primary tool available to the President's Science Advisor is persuasion. How effective he is in convincing agencies to shape or modify their R&D budgets depends largely on the strength of his personal relationship with inner circles of the White House.[17]

Two general comments can be made about the roles of these advisory bodies for the next decade. First, global problems such as climate change and pollution involve issues of cooperation and planning, while President Bush's goals for science and mathematics achievement by the year 2000 highlight the urgency of education and human resources for the Nation's vitality. Both will require domestic policy coordination, and tough research funding tradeoffs may be needed. Second, while the role of science advice will not wane in the 1990s, it is unlikely that the role of the Science Advisor, OSTP, or PCAST will be strengthened legislatively. To some, OSTP has to "... brighten its image on the White House political screen."[18] Yet, in the executive branch where influence is often equated with budgetary control, the advantage resides primarily with the research agencies and OMB.

Photo credit: Jamie Notter, OTA staff

The Old Executive Office Building is home to much of the Office of Science and Technology Policy and the Office of Management and Budget.

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[15] Created by President Eisenhower in 1957 after Sputnik, the President's Science Advisory Committee (PSAC) relocated science advice from the Office of Defense Mobilization to the White House. Among its first actions, PSAC proposed establishing a counterpart group of representatives from the Federal research agencies to improve coordination of the Nation's R&D effort. The result was the founding, in 1959, of the Federal Council for Science and Technology. See Ralph Sanders and Fred R. Brown (eds.), *Science and Technology: Vital National Assets* (Washington, DC: Industrial College of the Armed Forces, 1966), ch. 5, especially p. 76.

[16] See Jeffrey Mervis, "PCAST Members Ready to Speak; President Seems Ready to Listen," *The Scientist*, vol. 4, No. 10, May 14, 1990, pp. 1, 14-15. One role that the President's Council of Advisors in Science and Technology has already played is defining a pool of eligibles for key R&D agency posts. From among its 12 members, President Bush nominated physicist Walter Massey to head the National Science Foundation and cardiologist Bernadine Healy as director of the National Institutes of Health.

[17] Morone, op. cit., footnote 5, p. 6.

[18] Some say this is already occurring under Science Advisor Bromley, who is the first Science Advisor elevated to the title of Assistant to the President. Robert Rosenzweig quoted in "A Good Budget for Science, But Troubles Lie Ahead," *Science and Government Report*, vol. 20, No. 18, Nov. 15, 1990, p. 2.

Office of Management and Budget

Research budgets are strongly influenced within the Executive Office of the President by OMB. As Science Advisor Bromley has remarked: "It became evident a long time ago that if you control the budget, you control public policy. This is one of the facts of life that a science advisor must learn, that OMB is a tough player and not necessarily sympathetic."[19] OMB crafts the budgets of research programs to reflect the priorities of the President,[20] and helps to set realistic targets for the next year's budget in all research programs while attempting to balance the competing needs of the Federal departments and agencies.

The manner in which these concerns are negotiated with the agencies is left to the discretion of the OMB budget examiners. Budget examiners concerned with research are located in at least three of its six divisions: Natural Resources, Energy, and Science (which includes NSF, agriculture, and space); Human Resources, Veterans, and Labor (which includes health and education); and National Security and International Affairs (defense). Through Special Analysis J, OMB traditionally presented proposed R&D agency budgets for the new fiscal year. The publication of this analysis was discontinued after the fiscal year 1990 budget, but since that time, R&D has been discussed (with the information traditionally presented in Special Analysis J) in a separate introductory chapter to the President's budget.[21]

OMB's role in research priority setting and fiscal allocation is not public. The deliberations of the agency are internal, building on agency submissions preliminary to OMB decisions (see box 3-A). Behind-the-scenes negotiation between OMB examiners and agency budgeters is common. This closed-door policy minimizes contention, and perhaps stifles controversy, both within and without the government on specific funding issues.

A strong perception of OMB standards and policies on research has grown up outside of OMB and the executive branch. Most importantly, many observers state that OMB has an active role in deliberations over research agendas, particularly in support of projects such as the Space Station and the SSC. New programs, especially Presidential initiatives such as the Moon/Mars mission, require that OMB be involved early in the fiscal process.[22] But because these deliberations are shielded from public view, critics claim that these policies are not sufficiently debated.

The fiscal 1991 budget act placed a separate cap on discretionary spending in three budget categories: defense, domestic, and international programs. These caps limit spending for each of fiscal years 1991 through 1995 and specify methods of enforcing deficit targets.[23] The caps will force tradeoffs *within* each category of the budget; this will effectively reduce flexibility and foster more negotiation within the executive branch (i.e., among OMB, OSTP, and the agencies) in the allocations for specific programs.[24] Members of OMB staff also stress, however, that these caps will force greater priority setting based on the research issues, because the overall spending levels will be set.[25] Observers agree that the Omnibus Budget Reconciliation Act of 1990 has enhanced OMB's authority relative to Congress because OMB ". . . will have a final say on cost estimates for all programs."[26] (For further information on the budget act, see box 3-B.)

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[19] Mervis, op. cit., footnote 10, p. 3.

[20] Under President Bush, the Federal Coordinating Council for Science, Engineering, and Technology and the Science Advisor have participated in the implementation of several Presidential priorities. For the fiscal year 1991 budget, they included global climate change, high-performance computing, and mathematics and science education.

[21] These analyses, in turn, form the basis for an analysis and spring colloquium on the R&D budget, held in Washington, DC, and presented by the American Association for the Advancement of Science. These proceedings, edited and published the following fall, serve an important interpretive function for the scientific community, relating the budget to topical issues in science and technology. For the 15th annual proceedings, see Susan L. Sauer (ed.), *Science and Technology and the Changing World Order* (Washington, DC: American Association for the Advancement of Science, 1990).

[22] Hugh Loweth, "Science Advising and OMB," *The Presidency and Science Advising*, vol. 3, Kenneth W. Thompson (ed.) (Lanham, MD: University Press of America, 1987).

[23] See "Title XIII—Budget Enforcement," *Congressional Record—House*, Oct. 26, 1990, pp. H 12743-H 12744.

[24] Karl Erb, Office of Science and Technology Policy, personal communication, November 1990.

[25] Robert Grady, associate director, Natural Resources, Energy, and Science, Office of Management and Budget, personal communication, Feb. 7, 1991.

[26] See Thomas J. DeLoughry, "Deficit-Reduction Plan Could Tighten Budgets for Student Aid and Research," *The Chronicle of Higher Education*, vol. 37, No. 10, Nov. 7, 1990, pp. A18, A28.

Box 3-A—OMB and the Research Budget

The Office of Management and Budget (OMB) reviews the budgets of all Federal agencies before submission of the President's budget to Congress and performs crosscutting budget analyses, especially for topics of particular interest to the President. Traditionally, OMB has been very supportive of research in the Federal budget. This reflects the importance attached to research and development (R&D) in the budgeting process and the overall real and symbolic value of Federal research support as an indicator of future planning and direction in government investments.

Under President Bush and OMB Director Darman, the process of planning the research budget has changed. Before the budget is collated, R&D is the subject of several separate briefings and detailed analyses of issues concerning research initiatives (e.g., funding for individual investigators and big science projects on a case-by-case basis). The Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) committees and the Science Advisor have also participated extensively in the implementation of programs in several Presidential priority areas, especially global climate change, high-performance computing, and mathematics and science education. Important criteria for R&D investment used by OMB include the support of excellent science and engineering, long-term competitiveness and economic concerns, commercial spinoffs, national prestige, and "national security"—in the broadest military and economic sense.[1]

In the budget process for fiscal years 1991 and 1992, OMB asked the research agencies to submit budgets at five levels of funding, which include scenarios with real cuts as well as augmented funding. In addition, OMB requested that, for areas of particular Presidential interest, agency budget requests be ". . . described and justified relative to the goals, objectives, and research priorities . . ." outlined in various framework documents, such as the U.S. Global Change Research Program.[2] In areas not of highest priority, less crosscutting analysis is performed, and the manner in which these concerns are negotiated with the agencies is left more to the discretion of OMB budget examiners.

Tradeoffs are made among agency programs, and between the "research budget" and other areas of domestic discretionary funding. Under the new budget agreement, when OMB "passes back" the agency budgets after the first review, OMB has budgeted up to the caps determined for the agencies. If an agency wishes to increase specific levels of funding, decreases to the agency budget must also be specified to allow the total budget to remain under the spending cap. Tradeoffs are then made explicitly among agency programs.[3]

In summary, OMB provides a unique crosscutting function in research budgeting within the executive branch. Under President Bush, the implementation of research priorities has been accompanied by an increased role for the Science Advisor and the FCCSET committees.[4] In addition, general research priority setting has been elevated in the presentation of the President's budget. However, priority setting unrelated to targeted Presidential concerns remains primarily at the discretion of the budget examiners for the specific agencies, and tradeoffs are within agency budgets.

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[1] OTA meeting with Robert Grady, Joseph Hezir, and Jack Fellows, Office of Management and Budget, Feb. 7, 1991.

[2] Robert E. Grady, Associate Director, Natural Resources, Energy, and Science, Office of Management and Budget, "Terms of Reference Memorandum on the FY 1992 U.S. Global Change Research Program," unpublished document, June 18, 1990.

[3] The Darman Office of Management and Budget (OMB) was said to consider R&D as yielding especially high future returns on Federal investment. To this end, the process instituted by OMB encourages the research agencies to develop coherent proposals and discourages both within-agency disagreements and unresponsiveness of an agency to the requests of either OMB or the Office of Science and Technology Policy. Ground rules and deadlines are spelled out in the "terms of reference" issued by OMB in every priority area designated for an agency crosscut.

[4] Part of this increased Office of Science and Technology Policy (and Office of Management and Budget-reinforced) role has led to requests of the agencies for evaluative data. Of special relevance to this OTA report is the information gathering in progress on the "structure of science," an activity of the Federal Coordinating Council on Science, Engineering, and Technology Committee on Physical, Mathematical, and Engineering Sciences.

External Advice and Interest Groups

Much scientific and technical advice is solicited from the scientific community by the executive branch. This partnership between the scientific community and government has led to a complex policy structure that takes into account a range of views on many decisions. Active debate occurs both informally and within the scientific literature on programs, policies, and projects initiated by the Federal Government, and this debate often influences government decisions.

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Box 3-B—New Layers of Complexity for the Federal Budget

A budget process many critics had said was too complicated has become even more so, thanks to sweeping changes adopted by Congress and approved by President Bush.[1] Here are the major revisions to the 1985 Balanced Budget Act that will dramatically alter the way the budget will be drafted through fiscal 1995.

Discretionary Spending

For fiscal years 1991 to 1993, the law establishes separate ceilings for each of three categories of discretionary spending: defense, international aid, and domestic programs. If Congress chooses to increase spending for any discretionary program, it must offset the increase by cutting spending within the same category.[2] If it fails to make an offsetting reduction, an automatic spending cut—a sequester, in budget jargon—would slice enough from all other programs in that category to bring spending to below the ceiling.

The spending caps, in billions of dollars, are as follows (BA is budget authority, the amount Congress authorizes the government to spend in current or future years; O is outlays, the actual spending expected in each year):

	1991	1992	1993
Defense			
BA	$288.9	$291.6	$291.8
O	297.7	295.7	292.7
International			
BA	20.1	20.5	21.4
O	18.6	19.1	19.6
Domestic			
BA	182.7	191.3	198.3
O	198.1	210.1	221.7

For fiscal years 1994 to 1995, the new law establishes a single pot of money for all discretionary spending. The White House and Congress will have to decide how to allocate that money between the three spending categories. Spending above that overall limit would trigger a sequester to bring spending down to that ceiling. Total discretionary funds for those two years, in billions of dollars, are as follows:

	1994	1995
BA	$510.8	$517.7
O	534.8	540.8

Pay-as-You-Go Spending

Under the new law, Congress is required to offset the costs of any new entitlement spending programs and any tax reduction legislation. If Congress creates an entitlement program or tax benefit that is not "revenue neutral"—not financed by an offsetting tax increase or spending cut—it would then have to adopt a deficit cutting "reconciliation" bill to find the needed savings. Failing that, a sequester would cut enough from all other entitlements (except those, such as social security, that are already exempt from the "sequester" under the 1985 Balanced Budget Act) to make up the difference.

Adhering to broad sentiment in Congress, the new law takes the social security trust funds out of the deficit calculations. As a result, the funds' growing surpluses will not be used in determining whether the government has met its annual deficit targets. That is a victory for those who complained that the trust fund surpluses were masking the budget deficit's true size.

Sequesters

Unlike the 1985 law, which called for a sequester in October of each year in which Congress failed to meet specific deficit targets, the new law creates a schedule under which sequesters can occur several times a year for discretionary programs and once a year for entitlements and tax cuts.

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[1] The following is an edited version of "Adding New Layers of Complexity to Budget," a box appearing in Lawrence J. Haas, "New Rules of the Game," *National Journal*, vol. 22, No. 46, Nov. 17, 1990, p. 2796.

[2] The defense category, however, does not include the costs of Operation Desert Storm in the Persian Gulf, which the law assumes Congress will finance separately.

Continued on next page

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Box 3-B—New Layers of Complexity for the Federal Budget—Continued

First, a sequester directed at budget-busting appropriations bills can be triggered, if required, within 15 days of the end of a session of Congress. Second, a sequester can occur within 15 days of the enactment of such appropriations bills if the enactment takes place before July 1. Third, if those appropriations bills are enacted after July 1, a sequester would be applied to spending bills for the next fiscal year, which begins on October 1.

For entitlements and tax cuts, the law calls for a one-time review of all bills to determine whether they will, in total, increase the deficit. If they will, nonexempt entitlements would be sequestered at the same time as the end-of-session appropriations.

Deficit Targets

The new law sets deficit targets for the next 5 fiscal years. They are (in billions of dollars):

1991	$327
1992	317
1993	236
1994	102
1995	83

For fiscal years 1991 to 1993, the targets are not binding on the White House and Congress. Along with the spending caps for defense, international aid, and domestic programs, they will be adjusted to account for changes in economic and technical assumptions. For fiscal years 1994 to 1995, the President may adjust the deficit targets, if he chooses, for economic or technical reasons. If he does not adjust them, failure to reach those targets will trigger a sequester like that required under the 1985 budget law.

Scorekeeping

Furthering a trend that began when the Balanced Budget Act was revised in 1987, the Office of Management and Budget (OMB) has been given additional authority to tabulate the cost of tax and spending legislation. Previously, OMB had the power to decide whether, based on the costs of all such legislation and other factors, a sequester was required. But the Congressional Budget Office and Congress's Joint Committee on Taxation had the duty of tallying the costs of each tax and spending bill as it moved through Congress. Now, OMB's cost calculations will be binding on Congress.

While the Science Advisor and numerous advisory committees allow the scientific community, or more accurately, the various research constituencies within it, a voice in government decisions, other channels also exist to influence Federal policy. An unrivaled source of authority is the independent, congressionally chartered (in 1863) National Academy of Sciences (NAS). The presidents of NAS, the National Academy of Engineering, and the Institute of Medicine act as opinion leaders and buffers between the science community and the Federal Government (discussed further in chapter 5). Both the executive branch agencies and Congress call on (and pay for) NAS to conduct studies on issues of some urgency and importance in science, technology, and medicine.[27] The academies' elected membership of eminent specialists, working through panels and commissions, lends credibility to the reports they issue.[28]

Various interest groups have also traditionally played major roles in the formulation of Federal research funding and regulatory policy. Of an estimated 6,000 public and special interest groups active in Washington, many have a stake in some aspect of the diffuse Federal research activities.[29] Prominent interest groups that lobby on behalf of science include many industrial groups, professional societies, the higher education associations, and other more specialized groups that encourage research in targeted areas, such as the environment or health.

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[27] And the congressional appetite has grown from 9 National Academy reports mandated by the 95th Congress (1979 to 1980) to 24 by the 101st. See "Congress Hungry for NAS Advice," *Science*, vol. 250, Dec. 7, 1990, p. 1334.

[28] For a definitive look at the National Academy of Sciences as a social institution, see Phillip Boffey, *The Brain Bank of America* (New York, NY: McGraw-Hill, 1975). The National Academy Press also publishes a quarterly journal, *Issues in Science & Technology*, which provides a policy forum for an array of opinion leaders in and out of government. The National Research Council's (NRC's) *NewsReport* also provides a record of National Academy of Sciences' studies undertaken by NRC.

[29] Deborah M. Burek et al. (eds.), *Encyclopedia of Associations*, vol. 2 (Detroit, MI: Gale Research, Inc., 1989).

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As discussed below, interest group lobbying is most often associated with the legislative branch since the congressional decisionmaking process is more open and decentralized. However, lobbying of executive agencies also occurs and can sometimes have a significant effect on specific research programs. For example, program managers at the Agricultural Research Service in the U.S. Department of Agriculture (USDA) and at the Conservation and Renewables Office in the U.S. Department of Energy (DOE) state that agribusiness and energy industry lobbies, respectively, play a large role in setting agency priorities. In the current system, this involvement is important, because agribusiness and the energy industries are considered the eventual clients of these programs. Interest groups can also provide additional technical information (which may not be available to agency personnel) that can be used for decisionmaking, and they can influence the development of debate on specific programs. Outside interest groups can be seen as an informal extension of the advisory committee system and can be very beneficial to agency operations. However, in a more ideal system, the influence of interest groups and their interactions with the government would be made more public.[30]

After the executive branch agencies, OMB, and others produce the President's budget, it goes to Congress. Research program budgets and their accompanying support documentation are subsequently reinterpreted by congressional committees to determine agency priorities (e.g., increases over inflation or predicted spending targets in specific programs are interpreted as strong executive branch support, while corresponding decreases are interpreted more negatively). Congress then has an opportunity to comment on and change these priorities.

The Legislative Branch

Congress has traditionally been very supportive of the research enterprise in the United States, and rarely do debates over research issues divide along partisan lines. In particular, there has existed over at least the last 30 years a broadly shared supportive ideology covering goals, values, programmatic priorities, and rationales. The same arguments about health, economic competitiveness, and national prestige are part of members' arguments about science policy from all ideological perspectives.[31] Nevertheless, emphases given to specific programs have varied over the years.

During the 1960s, research was perceived as a means of increasing national prestige, enhancing security, and providing benefits. The goals of outdistancing the Soviets and maintaining a leadership position in the world through research were supported by Democrats and Republicans, liberals and conservatives, hawks and doves. However, while some members were convinced that research monies for defense could be better spent on domestic problems, others believed that direct expenditures on defense research would be more effective for boosting the economy and national defense.

During the late 1960s and early 1970s, science was burdened with greater material expectations, especially after the success of the Apollo Moon program.[32] Preservation of national preeminence remained a strong goal on all fronts, but different groups stressed different tangible rewards. The Democratic party platform in 1972 argued that research should protect the environment and improve employment for scientists.[33] In the same year, Republicans sought a science that would improve U.S. economic competitiveness internationally.[34] Liberals and conservatives clashed over the pace and extent of environmental initiatives. However, these disagreements were most often expressed over specific programming rather than the importance of a clean environment.

During the mid- to late 1970s, Democratic and Republican priorities diverged, despite agreement on some specific program areas. For example, 1976 Democrat and Republican party platforms supported energy research. However, the Democrats made a case for government investment, calling for "... major

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[30] See the Byrd Anti-Lobbying Provision (Public Law 101-121).

[31] Birdsell and Simons, op. cit., footnote 7.

[32] See J.W. Fulbright, "Is the Project Apollo Program To Land Astronauts on the Moon by 1970 a Sound National Objective?" *Congressional Digest*, vol. 44, February 1965, pp. 47, 49, 51, 53; and Barry M. Goldwater, "Is the Project Apollo Program To Land Astronauts on the Moon by 1970 a Sound National Objective?" *Congressional Digest*, vol. 44, February 1965, pp. 53, 55.

[33] Bruce D. Johnson, *National Party Platforms: Volume II, 1960-76* (Urbana, IL: University of Illinois Press, 1978), pp. 802-803.

[34] Ibid., pp. 876-877.

Photo credit: Michael Jenkins

Two members of the Senate Committee on Energy and Natural Resources, which has jurisdiction over the research programs at the Department of Energy and Interior, confer.

initiatives, including major governmental participation in early high-risk development projects. . . .''[35] The 1976 Republican party platform detailed the importance of maintaining a balance among private, university, and government efforts at scientific research. It pledged to ''. . . support a national science policy that will foster the public-private partnership to insure that we maintain our leadership role.''[36] This position in the Republican platform was deepened considerably in OMB's *Issues '78*, which accompanied President Ford's final budget.[37] *Issues '78* stressed the importance of leaving a role for the private sector and avoiding government involvement in readying technologies for commercial development.

During the 1980s, Republicans took the ''Issues'' agenda a step further, arguing that ''partnerships'' among government, universities, and industry were the best way to promote research, leaving all development issues to industry except in cases of a pressing defense interest. Democrats contested this rationale, arguing that a massive increase in the research funds oriented toward defense tarnished relations between the government and the scientific community.[38]

In general, Congress is empowered to be an architect of the research system. To implement or guide initiatives in the U.S. research system, Congress can adjust the research budget, craft legislation, or monitor and influence Federal agencies through the oversight function. (See appendix A for a summary of major legislation passed by Congress since 1975 affecting U.S. R&D.) Unfortunately, because it must consider the priorities set by the Federal agencies *after* they have been codified in the President's budget or *after* they have been acted on in a program, Congress' position has often been reactive rather than proactive.

The following describes the congressional committee structure, budget process, and the oversight function. These processes are well understood. The relatively new phenomenon of earmarking appropriations to universities (for eventual use in the conduct of research) is described in more detail.

The Congressional Committee Structure and the Budget Process

Almost one-half of the 303 committees and subcommittees of the 101st Congress claimed jurisdiction over some aspect of research.[39] While inhibiting development of coordinated public policy, this fragmentation has characterized the long history of Federal involvement in research. Furthermore, congressional history shows that Congress has generally chosen to decentralize decisionmaking further rather than to consolidate and coordinate the Federal legislative process.

The Committee System

Congress' internal party organizations in each house assign members to committees, considering their preferences, party needs, and the geographical

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[35] Ibid., p. 934.

[36] Ibid., p. 984.

[37] Office of Management and Budget, *Issues '78* (Washington, DC: U.S. Government Printing Office, January 1977).

[38] The Democrats have always been proponents of more active Federal intervention in R&D that affects the civilian economy. This can be traced to the Kilgore v. Bush debate of the late 1940s over the role of a national science foundation. Brooks, op. cit., footnote 9.

[39] Much of the following section is based on U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies and Management*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991). Also see Morris P. Fiorina, *Congress: Keystone of the Washington Establishment*, 2d ed. (New Haven, CT: Yale University Press, 1989).

Table 3-1—Congressional Authorization Committees and Appropriations Subcommittees With Significant Legislative Authority Over R&D

Jurisdictions of authorization committees: [a]	Agency
House:	
Agriculture	USDA
Armed Services	DOD, DOE
Energy and Commerce	DOE, ADAMHA, NIH, CDC, DOT
Interior and Insular Affairs	DOI
Science, Space, and Technology	NASA, NSF, DOE, EPA, NOAA, DOT, NIST, DOI
Public Works and Transportation	NOAA, DOT
Merchant Marine and Fisheries	USDA, NOAA, DOT
Veterans Affairs	VA
Foreign Affairs	A.I.D.
Senate:	
Agriculture, Nutrition, and Forestry	USDA
Armed Services	DOD, DOE
Commerce, Science, and Transportation	NSF, NASA, DOT, NOAA, NIST
Energy and Natural Resources	DOE, DOI
Labor and Human Resources	NIH, ADAMHA, CDC, NSF
Environment and Public Works	EPA
Veterans Affairs	VA
Foreign Relations	A.I.D.

Jurisdictions of appropriations committees: [a]	Agency
Labor, Health and Human Services, Education and Related Agencies	NIH, ADAMHA, CDC
HUD and Independent Agencies	NASA, NSF, EPA, VA
Energy and Water Development	DOE
Interior and Related Agencies	DOE, USDA, DOI
Agriculture, Rural Development, and Related Agencies[b]	USDA
Commerce, Justice, State, the Judiciary, and Related Agencies	NOAA, NIST
Transportation and Related Agencies	DOT
Foreign Operations	A.I.D.
Defense	DOD

KEY: ADAMHA=Alcohol, Drug Abuse, and Mental Health Administration; A.I.D.=Agency for International Development; CDC=Centers for Disease Control; DOD=U.S. Department of Defense; DOE=U.S. Department of Energy; DOI=U.S. Department of the Interior; DOT=U.S. Department of Transportation; EPA=U.S. Environmental Protection Agency; HUD=U.S. Department of Housing and Urban Development; NASA=National Aeronautics and Space Administration; NIH=National Institutes of Health; NIST=National Institute of Standards and Technology; NOAA=National Oceanographic and Atmospheric Administration; NSF=National Science Foundation; USDA=U.S. Department of Agriculture; VA=U.S. Department of Veterans Affairs.

[a] The jurisdictions of the authorizing committees are not exclusive. For this table, repeated authorization of a number of R&D-related programs was required to establish jurisdiction.

[b] The corresponding subcommittees of the Senate and House Committees on Appropriations have the same name with one exception: the Senate Subcommittee on Agriculture, Rural Development, and Related Agencies and the House Subcommittee on Rural Development, Agriculture, and Related Agencies.

SOURCES: Office of Technology Assessment, 1991; and Elizabeth Baldwin and Christopher T. Hill, "The Budget Process and Large-Scale Science Funding," *CRS Review*, February 1988, p. 15.

and ideological balance of each committee.[40] Most bills are referred to one standing committee, but the complexity of public policy issues means that major bills are often sent to multiple committees with overlapping jurisdictions. Individual committee rules determine a bill's subcommittee assignments, which also can overlap. Table 3-1 shows the committees with important legislative jurisdiction over research.

Overlapping committee jurisdictions can slow and even stall policy development and send mixed signals to the executive branch and lower levels of government. Committees that try to develop comprehensive research policies are often frustrated by the vested interests of their sister committees, executive branch agencies, and various research communities.

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[40] In the 101st Congress, the Senate had 16 standing committees and 87 subcommittees; the House operated with 22 committees and 146 subcommittees. In addition, the 101st Congress has 9 special or select (with 11 subcommittees) and 4 joint committees (with 8 subcommittees) whose functions are primarily investigative. The average Senate committee had five subcommittees, compared to seven in the House. Every House member, except top party leaders, served on at least one standing committee. Senators served on at least two committees.

Congressional committees have evolved into permanent bodies with authority to propose legislation, an independence that has given committees almost unassailable influence over legislation in their specialized areas.[41] Committee chairmen consequently wield enormous power.[42] They tend to be long-lived in their positions, holding them much longer than the terms of most presidents or Federal agency executives. This longevity allows committee chairmen to influence the long-term course of events in a particular area and to implement detailed agendas. However, some committees are better positioned on certain issues than others.

The Budget Process and the Authorization and Appropriations Committees

Authorizing committees in both houses report annual or multiyear authorization bills for Federal programs under their jurisdiction, thereby setting the maximum amount of money an agency may spend on a specific program. The exceptions are entitlement programs, such as social security and Medicaid, which operate under permanent authorization and are effectively removed from the authorizing process. Authorizing (or legislative) committees and subcommittees are influential through their oversight functions when major new legislation is first passed, when an agency is created or its program substantially modified, and when setting funding authorizations to initiate, enhance, or terminate a program. During the 1980s, deficit reduction laws and trends restricting spending, shortcomings in the budget process, and new programs greatly expanded the roles of the "money" committees—Appropriations, Budget, and Ways and Means on the House side, and Appropriations, Budget, and Finance in the Senate—at the expense of authorizing committees.

After the Presidential budget reaches Congress, the Budget committees in the House and Senate provide a concurrent resolution that sets an overall ceiling and limits for major spending areas, like health or transportation. Appropriation bills, originating within the House Committee on Appropriations and its 13 subcommittees, effectively control spending since authorized funds may not be spent unless they are also appropriated.

Photo credit: Michael Jenkins

Members of the House Committee on Agriculture debate the 1990 Farm Bill, which affected many research programs at the Department of Agriculture.

No less than nine subcommittees of Appropriations have jurisdiction over research. While these nine subcommittees will decide what monies are appropriated for research, the initial distribution of funds by the full committee among the subcommittees can have serious implications for research funding. For example, the Veterans Affairs, Housing and Urban Development, and Independent Agencies Appropriations Subcommittee is responsible for the budgets of NASA and NSF, or 35 percent of the civilian R&D budget. If this subcommittee is for some reason "left short," then science funding could suffer significantly as it competes with housing, veterans' affairs, and other programs. Furthermore, research budgets will be largely negotiated within the new "domestic" spending category, making decisions all the more difficult. As noted earlier, the Budget Reconciliation Act of 1990 establishes limits on discretionary spending by category (a new Title VI of the Congressional Budget Act of 1974). It also states:

> As soon as possible after Congress completes action on a discretionary spending . . . bill, and after consultation with the [House and Senate] budget

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[41] Judy Schneider, updated by Carol Hardy, *The Congressional Standing Committee System—An Introductory Guide* (Washington, DC: Congressional Research Service, May 1989), p. 2.

[42] This power was enhanced in the "House revolution of 1910," limiting the role of the Speaker by establishing seniority as the major criteria for determining committee chairmanship and moving up in its ranks. Ibid., p. 3. In battles of information where larger support staffs can determine the victor, committee chairmen have a distinct advantage with additional committee personnel.

> committees, the Congressional Budget Office (CBO) is to provide the Office of Management and Budget (OMB) with an estimate of the bill's effect on spending and revenues. . . . OMB is required to explain differences between its estimates and those of CBO.[43]

Some research agencies fared very well in the congressional appropriations process during the 1980s. For example, even under tight budgetary constraints, the National Institutes of Health was routinely given more money by the Labor, Health and Human Services, Education, and Related Agencies Subcommittee than the Administration had originally proposed.[44] USDA, and to some extent DOE, have also consistently received more in actual budget authority than allocated in the President's budget. Although in theory, policy and oversight is reserved for authorizing committees, appropriations committees frequently insert legislative provisions and funding for special projects into bills (see the discussion below on congressional earmarking). The appropriations committees' control over spending and the tendency to modify authorizing legislation creates tensions and intensifies intercommittee rivalries, particularly in the House where a smaller proportion of members serve on the Committee on Appropriations.

In Congress, jurisdiction or turf can mean additional staff, publicity, and power, prompting committees to seek broad jurisdictions and resist moves to narrow them, perpetuating conflicts and overlaps. Research issues are particularly susceptible to fragmentation and competition, because they cut a broad swath across national life. Historically, each issue has developed independently based on different goals and objectives, establishing supportive committee connections and constituencies that are hard to alter. Larger jurisdictional areas allow greater flexibility in linking issues within comprehensive legislation. However, they can also pit unrelated issues against each other for attention on a committee's agenda.

External Advice and Scientific Interest Groups

The congressional process is open and decentralized and is designed to incorporate public opinion. Like the executive branch, Congress solicits advice from scientific experts on many issues. This partnership and the active open involvement of the scientific community has lent strength to government decisionmaking on research.

In addition to solicited advice, scientific information is also offered by the thousands of public and special interest groups that actively lobby the Federal Government. These groups organize the opinions of their constituents. They employ technical experts to press their cases to Congress, testifying at hearings, providing privileged information, drafting model legislation, publishing and distributing reports, and meeting with members and staff. For example, in the global climate change debates in Congress, various environmental groups (both for and against action on global climate change) have presented comprehensive technical analyses detailing the current state of scientific knowledge and the most notable gaps. These analyses have influenced the allocation of monies for research in these areas.

The number of interest groups and politically active professional organizations increased dramatically during the 1970s and 1980s. This proliferation coincided with an expansion of congressional subcommittees, which provided more opportunities for lobbying and greater public participation in executive agency rulemaking.[45] While often seen as detrimental to the process, interest groups can furnish valuable information to debates and can present important arguments. Nevertheless, as with executive branch lobbying, because of the informal nature of the relationship of interest groups to

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[43] "Title XIII," op. cit., footnote 23, p. H12745. A later section on "scorekeeping" underscores the point: "Section 251(a)(7) and 252(d) of Gramm-Rudman-Hollings as amended by this conference agreement provides that the Office of Management and Budget must make its estimates in conformance with scorekeeping guidelines determined for consultation among the Senate and House Committees on the Budget, the Congressional Budget Office, and the Office of Management and Budget" (p. H12749). See Lawrence J. Haas, "New Rules of the Game," *National Journal*, vol. 22, No. 46, Nov. 17, 1990, pp. 2793-2797.

[44] American Association for the Advancement of Science, *Congressional Action on Research and Development in the FY 1991 Budget* (Washington, DC: 1990), p. 7.

[45] The research lobbies are a heterogeneous lot, ranging from, for example, the Industrial Research Institute, the Pharmaceutical Manufacturers Association, and Research! America to the education lobbies, such as the National Association of State Universities and Land-Grant Colleges and the Association of American Universities, and the Federal liaisons for the research universities who work closely with State congressional delegations.

Congress, interactions can appear unseemly. Every issue, including research funding, has a constituency and, therefore, special interests.[46]

Congressional Oversight

Congress has invested the executive branch with broad authority over the multitude of Federal agencies and programs. However, in 1946, Congress officially reaffirmed its responsibility for oversight in the Legislative Reorganization Act. In 1970, Congress required that House and Senate committees publish oversight reports every 2 years, and increased committee staff size. Congress further acted in the 1974 Congressional Budget and Impoundment Act to strengthen the role of the General Accounting Office (GAO—a congressional support agency) to acquire fiscal and program-related information.[47]

In addition, House committee rules adopted in 1974 stipulated that committees with more than 15 members (raised to 20 members in 1975) create oversight subcommittees or require that legislative subcommittees provide oversight. Legislative subcommittees can only carry out oversight within their jurisdiction, while oversight subcommittees operate within the full committee's jurisdiction.[48]

Oversight can be exercised through: 1) hearings and investigations; 2) the authorization and appropriations processes; 3) GAO audits and investigations; 4) other studies by congressional support agencies; 5) legislatively mandated periodic reporting from executive branch agencies to Congress; 6) the Senate confirmation process of high-level political appointees; 7) casework and constituent questions about Federal agencies; 8) creation of special task forces; and 9) informal, nonstatutory controls, such as informal contacts between agency personnel and congressional staff. Groups outside of Congress and the executive agencies aid these processes by providing information to Congress about potential and existing problems in the executive agencies.

Congressional oversight has been important in determining the budgets of specific research programs and encouraging coordination between the research agencies.[49] Congressional oversight addresses the problems of research management and priority setting. Recently, fraud and misconduct by scientists in federally sponsored research projects have also been a focus of congressional investigations.[50] Combined with the power of the purse, Congress has effective tools to initiate change within the Federal research system.[51]

One tool that has been increasingly used by Congress in the last decade is academic earmarking—the provision of funds as line items in the budget for specific research facilities and projects. Because this practice is seen as circumventing normal procedures, it has been a subject of heated debate within the scientific community and Congress.

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[46] Sometimes, the best strategy for serving that interest is disputed among the lobbyists themselves. All work behind the scenes; some also place advertisements in the *The Washington Post* and *The New York Times*. For example, see Joseph Palca, ''Grants Squeeze Stirs Up Lobbyists,'' *Science*, vol. 248, May 18, 1990, pp. 803-804.

[47] Congressional Quarterly, *Congressional Quarterly's Guide to Congress*, Michael D. Wormer (ed.) (Washington, DC: Congressional Quarterly Inc., 1982), pp. 459-462.

[48] In 1990, there were 11 House committees with oversight subcommittees: Armed Services; Banking, Finance and Urban Affairs; Energy and Commerce; Interior and Insular Affairs; Merchant Marine and Fisheries; Post Office and Civil Service; Public Works and Transportation; Science, Space and Technology; Veterans Affairs; Ways and Means; and Select Intelligence. In addition, there are four committees whose implicit function is oversight: Appropriations, Budget, District of Columbia, and Government Operations. The House rules also give seven committees special oversight abilities to cross jurisdictional lines: Armed Services; Budget; Education and Labor; Foreign Affairs; Interior and Insular Affairs; Science, Space and Technology; and Small Business. Three Senate committees had oversight subcommittees: Agriculture, Nutrition, and Forestry; Finance; and Government Operations. Two Senate committees have implicit oversight responsibilities: Appropriations and Budget. Together, the House and Senate committees have oversight over all of the R&D programs in the Federal agencies.

[49] See Morris S. Ogul and Bert A. Rockman, ''Overseeing Oversight: New Departures and Old Problems,'' *Legislative Studies Quarterly*, vol. 15, February 1990, pp. 5-24.

[50] See Marilyn J. Littlejohn and Christine M. Matthews, ''Scientific Misconduct in Academia: Efforts to Address the Issue,'' *CRS Report for Congress*, 89-392 SPR (Washington, DC: Congressional Research Service, June 30, 1989); Rosemary Chalk and Patricia Woolf, ''Regulating a 'Knowledge Business','' *Issues in Science & Technology*, vol. 5, No. 2, winter 1988-89, pp. 33-37; U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Investigations and Oversight, *Maintaining the Integrity of Scientific Research*, 101st Cong. (Washington, DC: U.S. Government Printing Office, January 1990); and U.S. Congress, House Committee on Government Operations, *Are Scientific Misconduct and Conflicts of Interest Hazardous to Our Health?* 101st Cong. (Washington, DC: U.S. Government Printing Office, September 1990).

[51] For an analysis, see Marcel C. LaFollette, ''Congressional Oversight of Science and Technology Programs,'' paper prepared for the Committee on Science, Technology, and Congress, Carnegie Commission on Science, Technology, and Government, New York, NY, September 1990.

Congressional Earmarking

Since the early decades of this century, powerful legislators, especially committee chairmen and ranking members, have made the congressional earmark (a specific project funded directly by congressional appropriation) a routine, albeit small, part of the process by which the Nation's budget is disbursed to regions, States, and districts. Through earmarks a range of goods and services are procured. The practice of congressional earmarking is now a well-entrenched and important component of this political system, and it has historically been regarded as a redistributive device that addresses fiscal inequities through legislative power.[52]

While earmarking has been a traditional funding mechanism in many areas of government spending, explicit ''academic earmarks'' appear to be a relatively new phenomenon, dating to the early 1980s.[53] That this funding mechanism has been extended to academic research is not surprising, given the geographical and other inequities in research funding. However, for the scientific community in which the ethic of peer review is so strong, earmarking is contrary to the established mentality of ''fair'' funding allocation. It signals a departure from the old social contract that delegated authority to representatives of the scientific community to judge technical merit and advise the Federal Government on research investments.[54]

What Is an Academic Earmark?

For the purposes of this discussion, OTA defines a congressional academic earmark as a project, facility, instrument, or other academic or research-related expense that is directly funded by Congress, which has not been subjected to peer review and will not be competitively awarded.[55] Among the largest examples of 1990 earmarks under this definition are the Soybean Laboratory at the University of Illinois-Urbana, the Waste Management Center at the University of New Orleans, a medical facility at the Oregon Health Sciences University, and a geology research project awarded to the University of Nevada system.

There are other definitions of academic earmarks.[56] One states that an earmark is any research project or facility *directly* funded by Congress. This definition implies that the executive branch role in setting budgets and priorities and administering the Federal Government's research programs is more valid than decisions made by Congress. Not surprisingly, some members consider this definition an insult to Congress. Another definition stresses that earmarks are projects that are initiated by Congress and receive appropriations, but not approved by authorizing committees. This definition reflects some members' view that the legislative process should work as is formally intended, i.e., authorizations should always precede appropriations. Consequently, this definition is sometimes used within Congress to oppose earmarking, as earmarkers violate the norms of the budget process.[57] Still other definitions seek to make exceptions for direct appropriations for projects in the Agriculture appropriations bill, because agricultural research is said to have a distinct culture where such projects are the norm. Finally, other definitions make a distinction between earmarks and direct appropriations for historically Black colleges and for other traditionally federally funded institutions such as Gallaudet University in Washington, DC.

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[52] John A. Ferejohn, *Pork Barrel Politics* (Stanford, CA: Stanford University Press, 1974), p. 252. One story has it that the word ''earmark'' derives from a practice as old as the Republic itself. Pigs' ears were cut off prior to the animals grazing in a common area with the pigs owned by others. Credit for a stolen or slaughtered pig could be established by possession of the physical evidence—the ''mark'' of the ear.

[53] Hugh Loweth, who retired after 35 years from the Office of Management and Budget (OMB) in 1986 as deputy associate director for energy and science, cites as the origin of the current wave of academic earmarks Science Advisor George Keyworth. In 1982, without consulting either with OMB or the materials research community, Keyworth attempted to insert $140 million in the Department of Energy budget as a ''Presidential initiative'' for a National Center for Advanced Materials at Lawrence Berkeley Laboratory in California. A storm of protest led, depending on the source, to a scaling back of the project or a temporary deferral by Congress. See Wil Lepkowski, ''Hugh Loweth, Key Science Policy Official, Retires,'' *Chemical & Engineering News*, vol. 64, No. 29, July 21, 1986, pp. 16-18; and Robert P. Crease and Nicholas P. Samios, ''Managing the Unmanageable,'' *The Atlantic Monthly*, January 1991, p. 88. Crease and Samios interpret the significance of this event this way: ''After that episode Congress lost the restraint with which it had traditionally approached the basic research budget. If Presidential initiatives were possible, it was argued, so were congressional initiatives, and universities began to lobby Congress directly for them.''

[54] See Richard C. Atkinson and William A. Blanpied (eds.), *Science, Technology, and Government: A Crisis of Purpose*, proceedings of a symposium, March 1988 (La Jolla, CA: University of California, San Diego, 1989), pp. 53-61.

[55] In this context, peer review refers to the competition of proposals for funds, which are rated by independent scientific experts selected to advise an agency. See ch. 4 for a more complete definition of peer review.

[56] What follows is based on James Savage, University of Virginia, ''Academic Earmarks and the Distribution of Federal Research Funds: A Policy Interpretation,'' OTA contractor report, July 1990. Available through the National Technical Information Service, see app. F.

[57] Congress is not of one mind on earmarking, and while many congressional representatives earmark, others are steadfastly opposed to it. See Dan Morgan, ''Nunn Says He'll Investigate Some Defense Bill Projects,'' *The Washington Post* Oct. 10, 1990, p. A4.

The Debate Over Congressional Earmarking for Research

Within much of the scientific community, academic research earmarking is disdained: it is seen as circumventing peer review, politicizing science, and reducing the quality of research by diverting funds that otherwise would be awarded competitively for facilities and projects.[58] However, no one claims that simply because a project was funded through earmarking that ipso facto it would produce bad science. There is in fact evidence that earmarks can produce well-respected research;[59] some universities have defended their earmarks by pointing to positive evaluations of the earmarked projects by the relevant Federal agency (after the project has been initiated). Opponents to earmarking state that, given limited Federal resources, many worthy projects are likely to be denied funding, and thus some means of evaluating and ranking *all* research proposals are desirable. Some appropriations subcommittees may seek the advice of the cognizant agency on the merits of an earmark before funding it, particularly on facilities projects, but there is no evidence that such advice is sought systematically.

Earmarks often originate with legislation proposed by powerful members of Congress and strategically placed members on specific committees. There is much benefit to obtaining an earmark, especially since such projects are a relatively inexpensive way to help ensure reelection by bringing Federal funds to the member's district. These members are thought to be able to stifle debate on the merits of these projects, or cooperation between members is thought to circumvent it. This lack of open debate is seen as potentially jeopardizing the quality of the projects funded by earmarks and contributes to the perceived waste of national resources.[60]

On the other hand, many support earmarking, claiming it as legitimate political decisionmaking without which fair distribution of Federal funds would never take place. Proponents contend that there must be a tradeoff between efficiency and distribution, and that policymakers must work so that a portion of the wealth can be distributed to poor areas of the country.[61]

Congressional earmarking must also be viewed in relation to the almost absolute power of executive agencies to disburse Federal monies (subject to oversight by Congress). By seeking support for a specific program or project, executive agencies can designate monies for specific geographical areas or institutions—much like an earmark. For example, the SSC is to be built in Texas. DOE is thus supporting research in a specific geographical area and in the institutions and groups that will participate in the creation of the SSC.[62] Congress wonders whether it is responsible democratic government to confine all direct spending power in the executive branch. If agency processes do not meet desired ends, many claim that there must be some method for Congress to directly correct inequities. Earmarks thus are seen by many—both inside Congress and out—as expenditures having merit in furthering socially justifiable goals.

As congressional earmarking is currently practiced, it can disrupt agency budgeting. If additional money is not set aside for earmarks, then funds that were planned by the agency for their new or continuing programs must be reallocated to cover the congressionally mandated expenditures.[63] For example, to cover earmarked projects in fiscal year 1989, DOE's Office of Basic Energy Sciences reallocated $20 million from programs it had planned.[64] To the extent that this is undesirable, it could be remedied if Congress would increase appropriations to cover the expense of earmarked programs or facilities. In addition, an earmark includes permission for the agency to spend less in another area (e.g., when Congress designates money for equipment at a specific university while also appropriating monies for programs that disburse funds to universities for the same type of equipment), and this tradeoff could be made explicitly in the congressional budget.

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[58] These arguments are reviewed in Daryl E. Chubin, "Scientific Malpractice and the Contemporary Politics of Knowledge," *Theories of Science in Society*, S.E. Cozzens and T.F. Gieryn (eds.) (Bloomington, IN: Indiana University Press, 1990), pp. 149-167. Also see Ken Schlossberg, "Earmarking by Congress Can Help Rebuild the Country's Research Infrastructure," *The Chronicle of Higher Education*, vol. 36, No. 19, Jan. 24, 1990, p. A48; and Bob Davis, "Federal Budget Pinch May Cut Amount of 'Pork' to Colleges Living Off of the Fat of the Land," *The Wall Street Journal*, May 2, 1990, p. A18.

[59] OTA interviews in the spring of 1990 at the Department of Energy (DOE) found that many earmarks of the early 1980s produced research centers highly regarded by some DOE program managers who had originally opposed them.

[60] U.S. General Accounting Office, *Budget Issues: Earmarking in the Federal Government* (Washington, DC: January 1990), p. 1.

[61] Earmarking can be in conflict with peer review, and perhaps should be. The two processes are *designed* to achieve different goals.

[62] Phil Kuntz, "Pie in the Sky: Big Science is Ready for Blastoff," *Congressional Quarterly Weekly Report*, vol. 48, Apr. 28, 1990, p. 1254.

There are few sources of academic earmarking information, and longitudinal data are even harder to compile.[65] Table 3-2 shows that for fiscal years 1980 to 1989 over 300 earmarks in appropriations bills for academic facilities and projects represented a total dollar value exceeding $900 million. In the fiscal year 1991 budget, at least $270 million was designated for earmarks.[66] The data focus on appropriations, reflecting the fact that most earmarks originate in appropriations rather than authorization bills. Eventually the focus of data collection and analysis will have to expand, however, because academic earmarks have appeared in authorizing legislation, and some are added in amendments to legislation on the House and Senate floors.

Academic Earmarks: Increasing Research Capacity and Equity?

Two issues have been linked to earmarking. The first is that the Federal Government has decreased its funding for facilities since the 1960s. Because many earmarks are specified for facilities construction, some argue that a Federal facilities program would decrease the frequency of earmarking in Congress.[67] However, since the potential demand for new facilities is so large, no Federal facilities program could immediately address all of the need, and earmarking would still be important to allow some institutions to receive facilities monies in advance of others. A similar argument holds for the earmarking of equipment.

The second issue addresses the most commonly stated reason for pursuing earmarked funds—that existing proposal review systems are biased in favor of certain institutions over others for the distribution of Federal funds. Academic institutions that are not research intensive (the so-called have-nots) seek earmarks to acquire the scientific infrastructure that gives research universities (the so-called haves) a competitive edge in winning research awards. Earmarking thus is seen as a means of reducing inequities

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[63] The Office of Science and Technology Policy identified over $800 million in congressional earmarks for R&D projects in the fiscal year 1991 budget. Over one-third of these came from accounts ''. . . that were either cut or held constant by Congress—which means that the money had to be taken directly from other projects.'' See Colin Norman, ''Science Budget: Growth Amid Red Ink,'' *Science*, vol. 251, Feb. 8, 1991, pp. 616-618, quote from 617.

[64] Corey S. Powell, ''Universities Reach Into Pork Barrel With Help From Friends in Congress,'' *Physics Today*, vol. 42, No. 4, April 1989, pp. 43-45.

[65] Sources include systematic listings in *The Chronicle of Higher Education* of institutions receiving earmarks, occasional stories in *Science & Government Report*, in the newsletter *Higher Education Daily*, and a recent study for the House Committee on Armed Services. A General Accounting Office (GAO) study of 17 Department of Defense projects ''. . . either congressionally mandated or established by the Army . . .'' included four projects that were ''. . . established non-competitively.'' However, the focus of the GAO report is oversight of university research and is not a comprehensive assessment of academic earmarks. See U.S. General Accounting Office, International Security and International Affairs Division, *Defense Research: Information on Selected University Research Projects*, GAO/NSIAD-90-223FS (Washington, DC: August 1990). The most comprehensive data on ''apparent academic earmarks'' have been assembled by James Savage for the Office of the President, University of California. They are based in part on Susan Boren, ''Appropriations Enacted for Specific Colleges and Universities by the 96th Through the 100th Congress,'' CRS Report 89-82 EPW, Feb. 6, 1989. See James Savage, Office of the President, University of California, ''The Distribution of Academic Earmarks in the Federal Government's Appropriations Bills, FY 1980-1989,'' mimeo, Mar. 7, 1989; and James Savage, Office of the President, University of California, ''Apparent Academic Earmarks in the FY 1990 Federal Appropriations Bills,'' mimeo, Dec. 19, 1989. Michael Crow, Iowa State University, personal communication, August 1990, insists ''. . . that there is currently no reliable data source from which to draw meaningful conclusions about the impact of academic earmarking. A comprehensive, well-defined effort is needed.'' OTA endorses the call for more systematic study.

[66] Eliot Marshall and David P. Hamilton, ''A Glut of Academic Pork,'' *Science*, vol. 250, Nov. 23, 1990, pp. 1072-1073. Another estimate comes from Colleen Cordes, ''Congress Earmarked $493 Million for Specific Universities; Critics Deride Much of the Total as 'Pork Barrel' Spending,'' *The Chronicle of Higher Education*, vol. 37, No. 24, Feb. 27, 1991, pp. A1, A21.

[67] For more on the issue of research facilities, originated through earmarks or not, see Congressional Research Service, *Bricks and Mortar: A Summary Analysis of Proposals To Meet Research Facilities Needs on College Campuses*, report to the Subcommittee on Science, Research, and Technology, Committee on Science, Space, and Technology, U.S. House of Representatives, 100th Cong. (Washington, DC: U.S. Government Printing Office, September 1987).

Table 3-2—Apparent Academic Earmarks: Fiscal Years 1980-89

Fiscal year	Dollar value	Number
1980	$ 10,740,000	7
1981	—[a]	—
1982	9,370,999	9
1983	77,400,000	13
1984	39,320,000	6
1985	104,085,000	36
1986	115,885,000	39
1987	113,800,000	41
1988	232,292,000	72
1989	202,537,000	87
1990	132,381,087	94
Total	$1,037,811,086	407

[a] The only direct appropriations in 1981 were to historically Black universities (three) and two other institutions within the District of Columbia, which Savage does not count as academic earmarks.

SOURCE: James Savage, Office of the President, University of California, "Apparent Academic Earmarks in the Fiscal Year 1990 Federal Appropriations Bills," mimeo, December 1989, table 1.

or leveling the playing field.[68] (See table 3-3 for a 10-year breakdown of earmarking by appropriations subcommittee.)

Congress is concerned with equity in all of the funds that it disburses. The historical concern within Congress over equity in science funding has centered on *geographical* equity, not the contemporary emphasis on *institutional* development. Geographical distribution suggests that certain institutions from each major region should be competitive in receiving Federal funding. In this manner, each region would have some opportunity to develop centers of excellence.[69] Institutional equity refers to the ability of *each* institution to be able to rise to prominence through Federal research funding. However, since there are 3,400 colleges and universities in the United States (1,300 that award science and engineering degrees, and 100 institutions that already command the largest share of Federal resources and produce most new Ph.D. researchers), the Federal Government faces a daunting task.[70]

The present situation is this: much like the stratified distribution of competitively awarded Federal research funds, academic earmarking over the last decade has primarily benefited a handful of States and academic institutions, although the total amount of earmarked dollars has been relatively small. Table 3-4 ranks the recipients of earmarked funds by States for fiscal years 1980 to 1989. More than 40 percent of these funds went to just 5 States, while two-thirds were awarded to only 10. The bottom 10 States received less than 10 percent of the earmarks.

> . . . 3 of the top 10 earmarkers include Massachusetts, New York, and Illinois, which rank in the National Science Foundation's list of top 10 State recipients of Federal research funds. . . . NSF's top 10 research States received more than a third of all earmarks.[71]

This same pattern of concentration is evident at the institutional level: 10 universities received nearly 40 percent of the earmarks during the last decade. (For the full distributions by State and by institution, see figure 3-2. For a ranking of institutions by Federal R&D funds awarded, see appendix B.)

A question for analysis might be: How have earmarked funds affected the research capability of the institutions receiving them? Between fiscal years 1980 and 1989, 20 academic institutions each received roughly $14 million in earmarked funds, or collectively 60 percent of the total earmarked dollars. But to determine the relationship between earmarking and research capability, other questions need to be addressed empirically: How have institutions used their earmarked funds? And if an institution improves its research capabilities and performance, as indicated by a change in its ranking of Federal research funds received or by its publication and citation output, is this due to the earmarks it receives? Or could it be that a university adminis-

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[68] See William C. Boesman and Christine Matthews Rose, "Equity, Excellence, and the Distribution of Federal Research and Development Funds," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Apr. 25, 1989). But evidence shows that even research-intensive institutions pursue earmarks.

[69] For evaluation of an early National Science Foundation program dedicated to this proposition, see David E. Drew, *Science Development: An Evaluation Study*, technical report presented to the National Board on Graduate Education (Washington, DC: National Academy of Sciences, June 1975).

[70] Science and engineering research requires a huge capital investment in facilities and instrumentation, followed by sustained operating support of that infrastructure, to attract and retain cutting-edge researchers. This capability in turn breeds success in the competition for Federal research funds. See Norman M. Bradburn, "The Ranking of Universities in the United States and Its Effect on Their Achievement," *Minerva*, vol. 26, No. 1, spring 1988, pp. 91-100. In fiscal year 1989, 100 institutions received 85 percent of Federal academic R&D funds. See National Science Foundation, *Selected Data on Academic Science/Engineering R&D Expenditures: FY 1989*, NSF 90-321 (Washington, DC: October 1990), and CASPAR database, table B-35.

[71] A list of 74 universities and colleges receiving more than $1 million in earmarked funds in fiscal years 1980 to 1989 can also be found in Savage, "The Distribution of Academic Earmarks in the Federal Government's Appropriation Bills," op. cit., footnote 65, pp. 6-7, 20-22.

Table 3-3—Apparent Academic Earmarks, by Appropriations Subcommittee: Fiscal Years 1980-90 ((number of projects) dollars, in millions)

Fiscal year	Total (all bills)	Energy and Water	Agriculture	Defense	Interior	Labor-HHS-ED	Treasury-Postal	VA-HUD Transportation	Independent Agencies	Commerce
1980	(7) $10.7	—	(5) $4.2	—	—	(2) $6.5	—	—	—	—
1981	—[a]	—	—	—	—	—	—	—	—	—
1982	(9) 9.4	(1) 1.1	(7) 7.3	—	(1) 1.0	—	—	—	—	—
1983	(13) 77.4	(1) 6.1	(3) 11.6	—	(4) 26.1	(5) 33.7	—	—	—	—
1984	(6) 39.3	(2) 10.0	(1) 1.0	(1) 0.8	—	(1) 19.0	—	(1) 8.5	—	—
1985	(39) 104.1	(9) 29.6	(16) 39.0	—	(7) 17.7	(4) 5.6	—	(1) 0.3	(1) 8.0	(1) 4.0
1986	(39) 115.9	(5) 35.3	(16) 15.5	(9) 39.8	(6) 16.5	(3) 8.8	—	—	—	—
1987	(50) 170.4	(9) 58.7	(21) 38.0	(9) 56.6	(5) 12.5	(3) 4.0	—	—	—	(3) 0.6
1988	(72) 232.3	(28) 128.3	(28) 49.2	(2) 28.5	(6) 6.3	—	(1) 4.0	(3) 8.6	(1) 1.7	(3) 5.6
1989	(87) 202.5	(9) 73.9	(49) 51.9	(3) 21.5	(6) 9.9	(2) 4.6	(9) 38.6	—	—	(9) 2.2
1990	(94) 132.4	(7) 37.5	(60) 47.5	—	(9) 6.3	—	(7) 23.1	(2) 5.0	(5) 10.2	(4) 2.8
Total	**(416) $1,094.4**	**(70) $380.4**	**(206) $265.2**	**(24) $147.2**	**(44) $96.3**	**(20) $82.1**	**(17) $67.7**	**(7) $22.4**	**(7) $19.9**	**(20) $15.3**
Percent of total	**100%**	**34.7%**	**24.2%**	**13.4%**	**8.8%**	**7.5%**	**6.2%**	**2.0%**	**1.8%**	**1.4%**

[a] The only direct appropriations in 1981 were to historically Black universities (three) and two other institutions within the District of Columbia, which Savage does not count as academic earmarks.

KEY: ED=U.S. Department of Education; HHS=U.S. Department of Health and Human Services; HUD=U.S. Department of Housing and Urban Development;
VA=U.S. Department of Veterans Affairs.

SOURCE: James Savage, Office of the President, University of California, "The Distribution of Academic Earmarks in the Federal Government's Appropriations Bills, Fiscal Years 1980-1990," mimeo, Mar. 7, 1989, table 2.

Table 3-4—Apparent Academic Earmarks Contained in the Fiscal Years 1980-89 Appropriations, Ranked by State (includes District of Columbia)

Earmark rank[a]	Earmarked funds	Percent of funds (cumulative)	Fiscal year 1988 Federal research rank[b]
1. Massachusetts	$92,416,000		4
2. New York	82,901,333		2
3. Oregon	78,150,000		26
4. Florida	62,377,000		16
5. Illinois	60,819,000	41.6%	7
6. Louisiana	56,700,000		30
7. South Carolina	37,700,000		33
8. West Virginia	34,423,000		43
9. Alabama	34,400,000		22
10. New Hampshire	30,045,000	62.9	34
11. Pennsylvania	26,800,000		6
12. Hawaii	25,317,500		35
13. Iowa	24,858,000		27
14. Mississippi	23,426,000		40
15. Arizona	22,575,000	76.5	25
16. California	21,740,000		1
17. North Dakota	20,259,333		44
18. Oklahoma	17,515,000		38
19. Washington	15,920,000		12
20. District of Columbia	15,020,000	86.5	29
21. Indiana	13,050,000		17
22. Texas	11,700,000		5
23. Nevada	11,100,000		41
24. Utah	11,000,000		23
25. North Carolina	9,900,000	92.8	9
26. Kansas	9,321,000		32
27. New Jersey	8,810,000		21
28. New Mexico	6,100,000		28
29. Ohio	5,700,000		10
30. Kentucky	5,304,000	96.7	37
31. Rhode Island	5,000,000		31
32. Maryland	4,350,000		3
33. Connecticut	3,750,000		14
34. Idaho	3,690,000		47
35. Wisconsin	3,550,000	98.9	11
36. Michigan	3,250,000		8
37. Minnesota	1,800,000		20
38. Vermont	1,450,000		39
39. Arkansas	1,200,000		45
40. Georgia	517,000	99.8	13
41. Virginia	450,000		18
42. Nebraska	315,000		36
43. Alaska	290,000		42
44. Missouri	225,000		19
45. South Dakota	195,333	99.9	51
46. Montana	50,000	100.0%	49
Total	$905,429,999		

[a] No earmarks were identified for the States of Maine, Tennessee, Delaware, Colorado, or Wyoming.

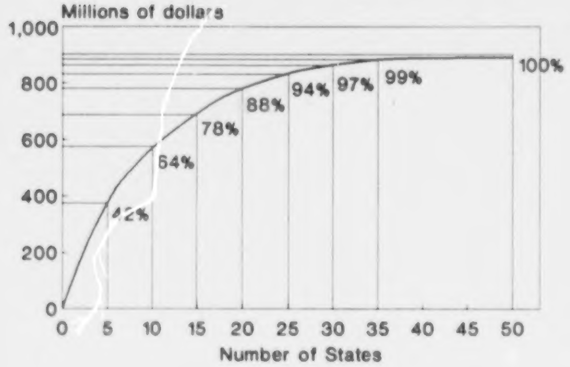
[b] Ranking in terms of Federal R&D expenditures at doctorate-granting institutions.

SOURCE OF FEDERAL RANKING: National Science Foundation, *Academic Science/Engineering R&D Funds, Fiscal Year 1988*, NSF 89-326 (Washington, DC: 1989), p. 32, table B-24.

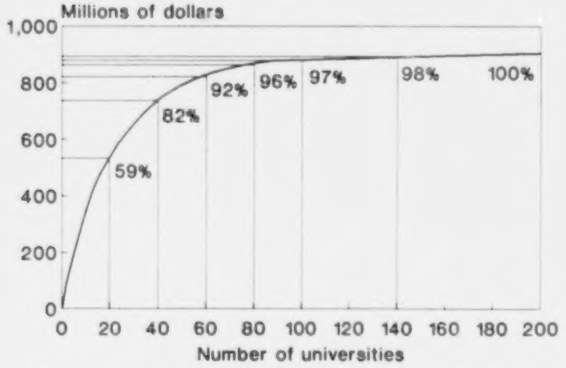
SOURCE: James Savage, Office of the President, University of California, "The Distribution of Academic Earmarks in the Federal Government's Appropriations Bills, Fiscal Years 1980-1990," mimeo, Mar. 7, 1989, table 2.

Figure 3-2—Apparent Academic Earmarks by State and at Universities and Colleges: Fiscal Years 1980-89

Cumulative distribution of academic earmarks, by State: FY 1980-89



Cumulative distribution of academic earmarks at universities and colleges: FY 1980-89



SOURCE: James Savage, University of California, Office of the President, "The Distribution of Academic Earmarks in the Federal Government's Appropriations Bills, Fiscal Years 1980-1989," mimeo, Mar. 7, 1989, tables 3 and 6.

tration that seeks earmarks is also engaged in a broader campaign to strengthen the research mission of the institution?

At present, there are no answers to these questions.[72] Nevertheless, data could be collected and the effect of earmarking evaluated over time.[73] If the results of these studies show that science performed in earmarked projects or with earmarked facilities or equipment is markedly inferior to other research projects supported under other agency programs, then steps could be taken to isolate problems inherent in earmarked projects. On the other hand, if these studies show that earmarked projects have an impact on research that is equal to (or even greater than) other projects supported through executive branch programs, then perhaps some of the concern over congressional earmarking is misplaced.[74]

Conclusions

This chapter has presented an overview of the highest level of decisionmaking for research in the Federal Government. Both the executive branch and Congress attempt to respond to changing national needs and potential research opportunities. However, due to their respective political agendas, modes of organization, and spheres of responsibility, they often disagree about the appropriate Federal role to pursue them.

The President, OMB, OSTP, Congress, and interest groups have separate roles in the decisionmaking process. They differ primarily in their concerns and priorities. For example, OMB is mostly concerned with fiscal issues, whereas OSTP is more concerned with coordination and comprehensiveness. Thus, long-term budgetary planning is very difficult.

In particular, the "research budget" is rarely considered as a whole in the Federal budget process. Separate parts of what might be considered the research budget are contained in many different budgets. Consequently, issues of concern to many parts of the research system are not considered across-the-board. "Nowhere in government is the

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[72] Institutions that have won earmarked money say its biggest impact is on their ability to recruit talented scientists. But it may also help to relieve the squeeze on research space, and in general upgrades the technical capabilities of the researchers involved. See Colleen Cordes, "Congressional Practice of Earmarking Federal Funds for Universities Offers Both Promise and Peril," *The Chronicle of Higher Education*, vol. 36, No. 17, Jan. 10, 1990, pp. A19, A24. It is too soon to tell how the quality of research produced at facilities created through earmarked funds compares with the research emanating from exclusively peer-reviewed, project-based academic centers.

[73] Crow, op. cit., footnote 65, points out that: "A single earmark can provide a university with the opportunity . . . for the development of relationships and personal acquaintances that might yield nonearmarked collaboration with that Federal agency in the future. A single earmark might provide the opportunity to develop new and continuing relationships with business and industry or State government. . . . Thus, while a university's total research funding may increase only marginally over a 5- to 10-year period (less than 5 percent) as a result of an earmark, the earmark might still have had substantial impact because of its impact on a specific program (e.g., a 50-percent increase in competitive funding over a 5- to 10-year period)." Also see "How Iowa State University Wins Millions in Earmarked Funds," *The Chronicle of Higher Education*, vol. 37, No. 24, Feb. 27, 1991, p. A21.

[74] However, the problem of regional inequity will remain regardless of earmarks. This could be addressed by both the executive branch and Congress.

Photo credit: Michael Jenkins

The Senate Committee on Energy and Natural Resources holds a public hearing.

big picture considered; nowhere is the overall health of U.S. science and technology a primary mission or responsibility."[75]

An important aggregation of the research budgets could occur in the congressional appropriations process. Earmarking is also one visible, albeit minor, means of congressional budget negotiation. In the next chapter, OTA introduces the major research agencies, their priority setting for research, and funding allocation mechanisms.

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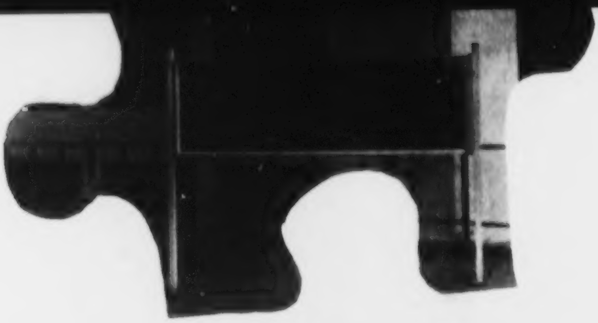
[75] Morone, op. cit., footnote 5, p. 12.



CHAPTER 4

The Federal Research System: The Research Agencies

DEPARTMENT OF ENERGY

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CHAPTER 4

The Federal Research System: The Research Agencies

Introduction

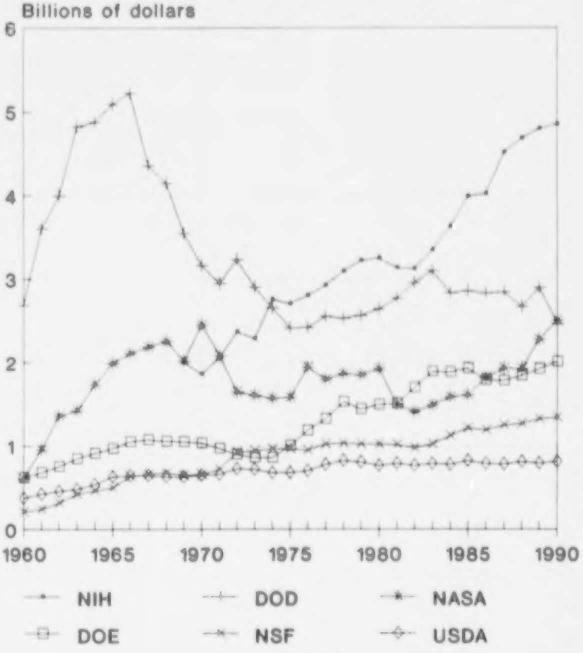
The effective management of the Federal research system depends on the quality of the research agencies and their staff. Over the last 30 years, as research budgets and the system have grown in size, the importance of these agencies in decisionmaking has increased.

Each agency has its own culture, which contributes not only to its success, but also embodies historically the "way things are done." Agency culture is thus a powerful determinant of future directions, with specific goals reflected in the collective knowledge of agency personnel. Pluralism and decentralization characterize each of the research agencies, with many separate programs pursuing diverse objectives. In particular, the lines of decisionmaking within an agency are more complicated than any organizational chart would suggest.

In preparing this report, OTA selected the six Federal agencies that fund most of the Nation's research. They are, in the order of their fiscal support of research (including basic and applied): the National Institutes of Health (NIH), the U.S. Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the U.S. Department of Energy (DOE), the National Science Foundation (NSF), and the U.S. Department of Agriculture (USDA)[1] (see figure 4-1). OTA reviewed historical budget figures for these agencies and conducted inperson interviews with agency personnel, ranging from top administrators, who interpret and set annual research priorities, to program managers, who disburse the funds. The interviews, 125 in all, yielded information on goal setting in the agency, proposal review, and methods of allocating funds. Interviews with National Academy of Sciences (NAS) staff (who are commissioned by research agencies to perform studies that will enhance decisionmaking) augmented the agency descriptions (see box 4-A).

OTA found that the research agencies generally attempt to follow their missions, as outlined in their founding charters and in subsequent legislation. However, congressional and executive views diverge on what is included in missions. There is also disagreement at many agencies over what constitutes a thoughtful, fiscally prudent, and expeditious

Figure 4-1—Research Obligations in the Major Research Agencies: Fiscal Years 1960-90
(In billions of 1982 dollars)



KEY: DOD = U.S. Department of Defense; DOE = U.S. Department of Energy; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture.

NOTE: Research includes both basic and applied. Before 1969, obligations for NIH were not broken out in this source. Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

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[1] Together these agencies supply roughly 95 percent of the Federal research budget. See Albert H. Teich and Kathleen Gramp, *R&D in the 1980s: A Special Report* (Washington, DC: American Association for the Advancement of Science, September 1988).

Box 4-A—OTA Interviews at the Federal Agencies

For this study, OTA sought data on the research goals of the six major Federal agencies that fund basic research: the U.S. Department of Defense (DOD), the U.S. Department of Energy (DOE), the National Institutes of Health, the National Aeronautics and Space Administration, the National Science Foundation, and the U.S. Department of Agriculture. In addition to collecting budget data, OTA performed 125 interviews with agency personnel ranging from top administrators who interpret annual budget priorities to program managers who disburse the funds. Interviews at the National Academy of Sciences and the Office of Management and Budget augmented the agency interviews.

Discussions centered on decisionmaking, priority setting, and funding allocation mechanisms. Typical questions that were asked included:

1. What are the stated goals for agency research monies and programs? What goals are not stated, but are implicit in the agency's mission? How have these goals changed since the 1960s? the 1970s? the early 1980s?
2. What processes (both formal and informal) are used in the agency to set priorities and goals for research monies? How has this process changed in the last 20 years?
3. How do new directions in research that are not anticipated get funded?
4. Does Congress set goals for the money that the agency allocates? Has this changed over time?
5. How do agency divisions coordinate with other parts of government?
6. What mechanisms are used to allocate funds? How do these mechanisms differ for extramural and intramural funding?

To illustrate the scope and depth of the interviews at the agencies, the interviews conducted at DOE can be used as an example. Interviews were conducted in five offices under the Secretary of Energy, and one laboratory was chosen as a case study. Excluding those interviewed at Los Alamos National Laboratory (LANL), four directors of offices at DOE headquarters, eight division directors, and five program managers were interviewed. Since the Office of Energy Research (OER) is the primary supporter of basic research at DOE, the Executive Director of OER, six division directors, and four program managers were interviewed. The Director of the Office of Weapons Research, Development and Testing; the Deputy Assistant Secretary for Renewable Energy; and one program manager in the Office of Conservation and Renewable Energy were interviewed. In addition, departmentwide priority setting was discussed with the Under Secretary for Policy, Planning, and Analysis, and the chief planner for research. Finally, budget data were discussed with the Deputy Director for Research in the Office of the Budget. At LANL, OTA staff toured the facility and interviewed the Deputy Director of LANL, the Director of the Meson Physics Facility, and the Deputy Director of the Health Research Laboratory, as well as a number of scientists and other members of the staff.

In all agencies, the offices that support research were identified, as well as those that participate in departmentwide planning. In addition, one or more inhouse laboratories were chosen for site visits. Summaries of the interview results were prepared and distributed to all interviewees for comment (with the exception of DOD, where a smaller set of reviewers was selected). Because the number of people interviewed had to be limited, the analysis sought only to illuminate the structure and diversity that characterizes executive branch decisionmaking in research. The table of organization was sampled to capture various perspectives on decisionmaking within and across the research agencies.

SOURCE: Office of Technology Assessment, 1991.

strategic plan to attain specific goals. Goals at the "macro level" (e.g., a Presidential call for more research and development (R&D) in a specific area) do not necessarily map neatly into agency missions, and some macro level goals cannot be addressed through current agency structures.

Agencies also have a good sense of their research constituencies (i.e., the scientists that receive agency funds), and of what their future directions and needs will be. However, programs managers must often make tough decisions within limited budgets about who to fund, whether to provide money for instrumentation or personnel, and whether to favor disadvantaged groups such as women, minorities, and young investigators. Competing goals of education, equity, and economic activity must be weighed in every program.

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OTA found that peer review, manager discretion, and combinations of these methods are used by the research agencies to distribute funds. Since the beginning of the 1980s, the distribution patterns of research funding have been under great scrutiny. It is not only a matter of *who* should receive the funds, but how they are allocated (e.g., individual investigator grants or block grants to centers, short-term or long-term projects).

In this chapter, the major research agencies are described, their priority-setting mechanisms outlined and compared, and their funding allocation mechanisms discussed. Agency planning efforts and direction from other agencies of the Federal Government and the scientific community are analyzed.

Priority Setting in the Federal Agencies

Federal agencies initiate, manage, and terminate programs. At each step in the process, agency personnel must decide which program, or component of a program, will take precedence. What follows is a brief introduction to each of the major research agencies and to their priority-setting mechanisms for research. The agencies are presented in descending order of their annual research budgets.

National Institutes of Health

NIH is the largest research agency in the Federal Government in terms of dollars awarded to basic and applied research. It is the principal biomedical research arm of the U.S. Department of Health and Human Services (HHS), funding biomedical and basic research related to a broad spectrum of diseases and health problems both in its own research facilities (the NIH laboratories) and in external organizations.

The missions of the institutes are reflected in their titles. There are categorical, or disease-oriented, institutes, such as the National Cancer Institute (NCI) or the National Heart, Lung, and Blood Institute (NHLBI). And there are institutes with a population-based research focus that is population based, such the National Institute on Aging. The exception to these categorizations is the National Institute of General Medical Sciences (NIGMS), which has no targeted responsibility other than general basic research.

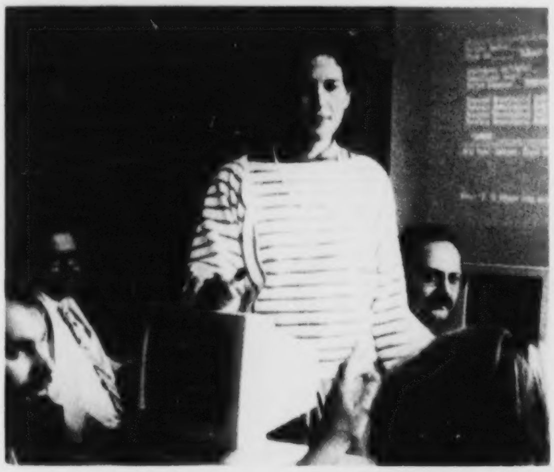

Photo credit: Research Triangle Institute

Researcher trains hospital staff for a National Institutes of Health (NIH)-sponsored clinical trial of medical therapies. Clinical trials are an integral part of NIH applied research.

NIH is part of the Public Health Service, so its work is very much tied to public health issues. Although NIGMS is devoted primarily to basic research, the categorical institutes conduct a range of research from basic to applied to development. For example, NCI's mission is to implement programs on the cause, diagnosis, prevention, and treatment of cancer. Often, the missions of the institutes overlap with each other or with other agencies. In these cases, a lead institute will coordinate. Because many of the institutes are categorical, NIH and Congress tend to set their research agendas epidemiologically, focusing their mission on diseases of highest prevalence. Critics of NIH question this approach, saying that it focuses the research agendas too much on the diseases of the majority, skewing research that could lead to health improvements in other areas.

Since the 1960s, the goals and justifications for health research have been fairly constant—improving the health of the American people, curing particular chronic diseases, and contributing to the economic well-being of the Nation by producing a healthier work force. However, particular emphases have shifted. During the early 1960s, mental retardation was emphasized by President Kennedy. In the 1970s, cancer and heart disease, which had been prominent research areas for decades, became even more important as President Nixon declared the War on Cancer in 1971. Vast sums of money were dedicated to attempts to eradicate these families of disease with mixed success. Although levels of funding remained high, by the late 1970s, the role of the environment in creating and reducing cancer risk replaced the earlier research focus on viral etiology and understanding cellular mechanisms.[2]

During the mid-1970s, the discovery of recombinant DNA shifted the emphasis of research once again, this time to biotechnology, which received increasing attention throughout the Reagan Administration. Most recently, treating and curing AIDS has been a dominant goal of NIH research. It first appears in the 1983 NIH budget authorization testimony,[3] and every year since then AIDS has received the largest increases in research funding within the NIH budget.

The fiscal year 1991 appropriation to NIH was just over $7.4 billion. NCI has the largest appropriation at $1.7 billion, followed by NHLBI at $1.1 billion. The National Institute on Deafness and Other Communication Disorders had the smallest appropriation at $135 million. See table 4-1 for budget histories of the various institutes from 1970 to 1990.

Each institute has an advisory council, which is appointed through HHS and is made up of scientists and lay people. Program officers must go before the council to present ideas for new programs, and councils review program balance. Each institute may also form advisory committees with programmatic foci; for example, NHBLI has six committees to assist in specific fields. Committees help develop new initiatives. It should be noted, however, that the council is only advisory, except for its ability to approve or disapprove grant applications.

When institute staff notice evidence of an emerging area of research, they assess the importance of the new field and gauge interest and capabilities. They can then convene a meeting or workshop, write up a proposal for a new program, and go to their council for approval. If the program does not have a known constituency, an institute will often issue a request for applications.

Some observers have criticized NIH in its response time to new research needs, such as AIDS and the Human Genome project. On the other hand, some scientists said NIH responded too quickly with its AIDS agenda. Interestingly, AIDS was incorporated into the existing NIH structure, with the National Institute of Allergy and Infectious Diseases (NIAID) taking the lead. The Human Genome project, which some argued belonged in NIGMS, was placed in the Office of the Director. Both approaches have been simultaneously criticized and hailed.[4] To date, there has been no mechanism for centralized planning at NIH. However, NIH, for the first time, is developing a strategic plan that cuts across all institutes. In addition, each institute submits its annual plan to the Office of the Director along with the budget. However, the Director has little authority to redirect the agenda of any institute. Through the budget process, Congress provides a coordinating function.

Despite growth in funding over the last decade, NIH views itself as being in a "steady state" and under enormous strain. After experiencing phenomenal growth (virtually a doubling of the budget in real terms during the 1980s), including an intramural budget that exceeds $900 million today, managers still feel they must juggle priorities, reorient existing programs, and make small, incremental changes in other programs—both intramural and extramural.[5] But there are exceptions: NIAID rose from seventh place among institute budgets to third place (from

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[2] Richard A. Rettig, *Cancer Crusade: The Story of the National Cancer Act of 1971* (Princeton, NJ: Princeton University Press, 1977); and Stephen Strickland, *Politics, Science, and Dread Disease* (Cambridge, MA: Harvard University Press, 1972).

[3] Mark Pollack, "Basic Research Goals: Perceptions of Key Political Figures," OTA contractor report, June 1990. Available through the National Technical Information Service, see app. F.

[4] With matrix management, some National Institutes of Health staffers said (in OTA interviews during the spring of 1990), the best way to respond to a new research initiative is to create a new associate director in the Office of the Director to coordinate efforts among the institutes. Also see Institute of Medicine, *The AIDS Research Program of the National Institutes of Health* (Washington, DC: National Academy Press, 1991); and Janice Long, "AIDS Research: More Funds, Coherent Strategy Needed," *Chemical & Engineering News*, vol. 69, Mar. 11, 1991, p. 4.

[5] Problems cited as besetting the National Institutes of Health (NIH) are: noncompetitive wages (especially for young researchers), increased politicization (notably over fetal tissue research and the use of animals for experimentation), "accountability fever" (centering on congressional investigations of purported misconduct in research and complaints about NIH's own process of inquiry), excessive paperwork to document research-related decisions, and lack of direction (the difference between an "acting" and a presidentially nominated, Senate-approved director). See Rick Weiss, "NIH: The Price of Neglect," *Science*, vol. 251, Feb. 1, 1991, pp. 508-511. The confirmation in March 1991 of Bernadine Healy as NIH Director filled a vacancy that existed since August 1989. See Larry Thompson, "NIH Gets Its First Woman Director," *The Washington Post*, Health section, Mar. 26, 1991, p. 8.

Table 4-1—National Institutes of Health History of Congressional Appropriations: Fiscal Years 1970-90 (In millions of constant 1982 dollars)

	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
NCI	$432.1	$814.6	$976.9	$1,207.1	$1,208.3	$1,166.7	$986.6	$1,004.3	$1,103.8	$1,211.3	$1,243.8
NHLBI	382.4	500.2	536.3	586.4	620.4	615.5	559.6	654.5	754.3	796.0	816.1
NIDR	68.6	93.3	81.5	81.3	85.5	79.7	72.0	82.4	90.7	104.1	103.3
NIDDK	313.8	329.7	284.4	284.5	360.5	398.1	368.2	430.8	499.8	440.8	442.5
NINDS	231.7	251.0	224.8	228.8	247.1	282.4	265.9	311.9	380.5	440.8	373.2
NIAID	231.7	234.6	205.7	201.1	224.8	251.3	235.9	296.8	336.7	526.6	633.9
NIGMS	353.1	373.1	311.7	296.8	319.7	364.6	339.9	386.2	452.0	521.6	518.9
NICHD	181.2	250.3	232.4	216.2	230.5	243.9	226.3	256.3	282.5	327.1	337.1
NEI	54.3	79.8	76.3	79.6	118.3	131.9	127.4	144.0	171.3	185.4	180.0
NIEHS	41.4	56.8	52.6	59.7	88.9	97.9	106.3	167.7	173.4	177.8	174.4
NIA	n/a	n/a	n/a	30.6	51.7	81.7	81.9	107.1	137.4	160.6	182.3
NIAMS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	121.8	128.5
NIDCD	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	89.5
NCNR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19.3	25.5
NCHGR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	45.3
Other	236.0	255.3	333.5	376.2	382.0	287.6	270.3	331.4	445.1	462.9	471.5
Total	2,526.2	3,239.1	3,315.6	3,648.3	3,937.5	4,001.1	3,640.2	4,172.3	4,620.0[a]	5,496.0	5,765.9[a]

KEY:

NCI	National Cancer Institute
NHLBI	National Heart, Lung, and Blood Institute
NIDR	National Institute of Dental Research
NIDDK	National Institute of Diabetes and Digestive and Kidney Diseases
NINDS	National Institute of Neurological Disorders and Stroke
NIAID	National Institute of Allergy and Infectious Diseases
NIGMS	National Institute of General Medical Science
NICHD	National Institute of Child Health and Human Development
NEI	National Eye Institute
NIEHS	National Institute of Environmental Health Sciences
NIA	National Institute on Aging
NIAMS	National Institute of Arthritis and Musculoskeletal and Skin Diseases
NIDCD	National Institute on Deafness and Other Communication Disorders
NCNR	National Center for Nursing Research
NCHGR	National Center for Human Genome Research

[a] Reflects enacted administrative reduction and sequestration.

NOTE: N/A=not applicable

SOURCE: National Institutes of Health, unpublished, February 1990.

almost $375 million to over $907 million) between fiscal years 1984 and 1991. AIDS research funds account for this increase, with one-half of the current NIAID budget devoted to research on the disease. AIDS funds are new money, and are not taken from other biomedical budgets.

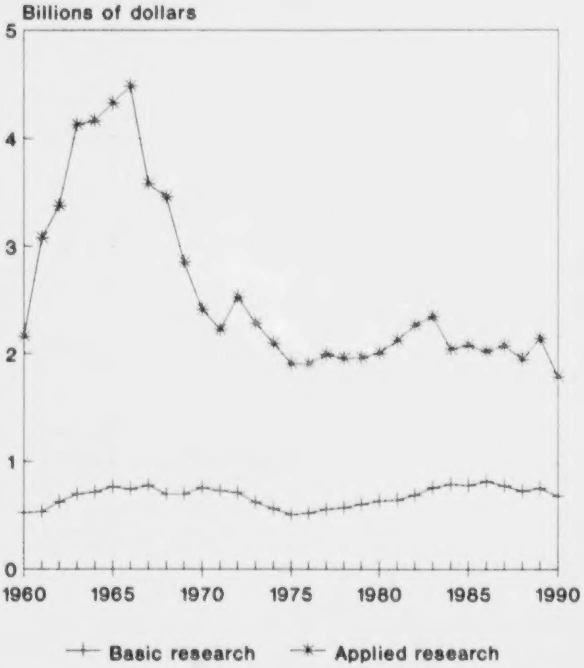
NIH is perpetually struggling to balance its research and public health missions. Some institutes are more responsive to one or the other, and therefore are oriented to individual investigators (and basic research) or centers (and clinical, disease-focused work), but all seek to serve both missions. What has been especially inconsistent is the NIH approach to public health or research crises. As noted above, while the AIDS initiative was assigned to one institute, Human Genome, originally assigned to the Office of the Director, is now a separate National Center for Human Genome Research that is not part of the Office of the Director. Many argue that one approach or the other responds better to crises while remaining supportive of, and responsive to, developments in basic research. Perhaps new efforts aimed toward a strategic plan could be used to better address public health and research crises.[6]

Department of Defense

DOD is the second largest source of basic and applied research funds in the Federal Government. Justification for defense R&D throughout the last three decades has been to stay ahead of the Soviet Union in the development of new military technologies. However, defense research is also inextricably linked to the expansion of knowledge and bolstering the overall U.S. technological base.

The military funds research through three categories: 6.1—research of the most fundamental nature; 6.2—applied research and exploratory development; and 6.3A—the initial stages of advanced development.[7] Research within DOD can be characterized by two phrases: "technology-push" and "requirements-pull." Knowledge gained from research creates areas for potential advancement, some of which were unforeseen when the research began. This new knowledge nudges the system to incorporate new ideas and thereby gain a greater level of capability (technology-push). At the same time, identified needs define areas for research and technological results to enhance the military. These requirements shape the directions of research and set the level of effort to be pursued (requirements-pull).

Figure 4-2—Basic and Applied Research Funds for DOD: Fiscal Years 1960-90 (In billions of 1982 dollars)



NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

Figure 4-2 presents the basic and applied (corresponding roughly to 6.1 and 6.2) research funds authorized for DOD from 1960 to the present.[8] Figure 4-3 graphs basic research funding in constant

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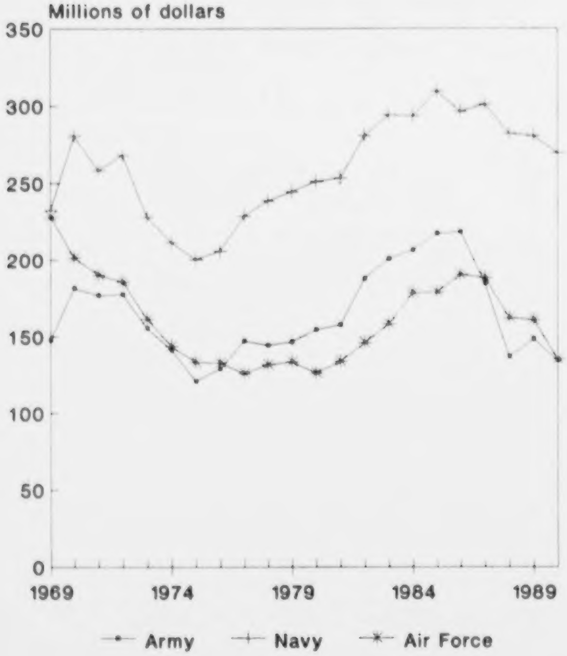
[6] See Institute of Medicine, *Funding Health Sciences Research: A Strategy to Restore Balance*, Floyd E. Bloom and Mark A. Randolph (eds.) (Washington, DC: National Academy Press, November 1990).

[7] The rest of the 6.3 category is devoted to more advanced development. U.S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base*, OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, March 1989).

[8] These data were collected by the National Science Foundation (NSF). Although some of the research agencies report problems with the NSF survey (discussed below), the Department of Defense already categorizes its research with 6.1 and 6.2 budget designations. Funds reported as "basic" and "applied" correspond to 6.1 and 6.2 funds, and their interpretation is fairly straightforward.

Figure 4-3—Basic Research in DOD by Service: Fiscal Years 1969-90 (in millions of 1982 dollars)

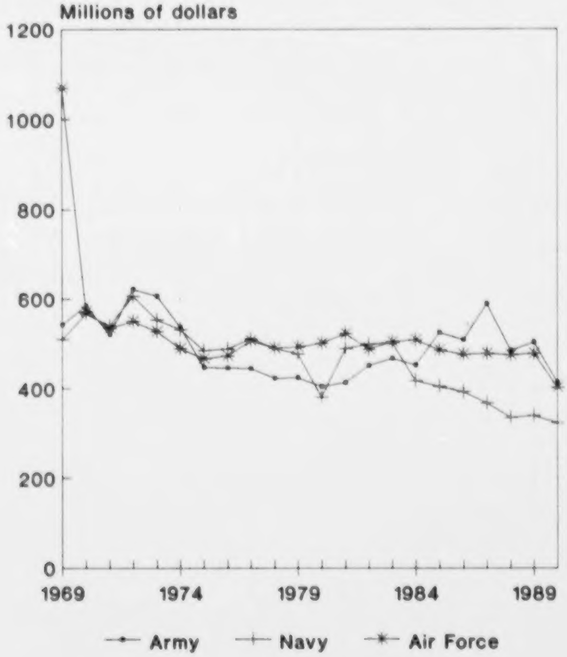


KEY: DOD = U.S. Department of Defense.

NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

Figure 4-4—Applied Research in DOD by Service: Fiscal Years 1969-90 (in millions of 1982 dollars)



KEY: DOD = U.S. Department of Defense.

NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

dollars for the three services, and figure 4-4 presents applied research funds by service from 1969 to the present. Compared with basic research funding for other research agencies, the services show remarkably little fluctuation in allocated funds, adjusted for inflation. The Navy has been consistently awarded more funds than either of the other services, roughly twice that of the Army or Air Force. Although applied research funding decreased in the late 1960s, it has remained even more constant than basic research in the 1970s and 1980s, and the three services have received almost identical levels of funding for applied research since 1970. Basic and applied research is also supported by the Strategic Defense Initiative Organization (SDIO—although SDIO funds are technically categorized as 6.3A) and the Defense Advanced Research Projects Agency (DARPA). These two organizations often cooperate with the three services to fund and operate research projects.

As recently stated by the Congressional Research Service:

> Although military basic research funding totals almost $1 billion annually, it (together with military applied research funding) has decreased since the mid-1960s in real dollar terms and relative to increases in total research, development, testing, and evaluation. Despite recent congressional action to increase military research budgets, executive branch decisionmakers have not sought large increases for research funding. As a result, critics say, too much attention goes to weapons development and too little to "creative" science needed to produce knowledge

vital to U.S. national security. Some allege that because of funding cutbacks the quantity and quality of military research may be decreasing.[9]

Recently each of the services concluded that a published strategic plan, explicitly covering their individual projections for the future technology base, would both aid in policy formulation and positively influence the budget for research. In the Air Force, it was called "Project Forecast II;" in the Navy, "Navy 21;" and, in the Army, "Army 21." Some of these plans take into account the "new reality" for the future: the decreasing likelihood of a European war, the increasing likelihood of low-intensity conflict (especially in the Third World and/or connected with drugs), increasing global economic and technological competition, the decreasing U.S. defense industry and R&D base, the decreasing supply of U.S. citizen scientists and engineers, and finally, decreasing defense budgets. Based on this future scenario, the plans identify key emerging technologies and areas for enhanced research.

The three services differ in the degree of centralization in the dispersal of 6.1 money. In the Air Force and the Navy, almost all 6.1 research monies flow through the Air Force Office of Scientific Research (AFOSR) or the Office of Naval Research (ONR), respectively. In the Army, 6.1 funds are more decentralized.

Army

Much of Army research is closely linked to priority setting for all of the R&D funds in the Army's laboratories and institutes. Laboratories in the Army act independently, although they determine priorities in relation to overall directives from Laboratory Command. With this independence comes requirements for a high level of accountability, and laboratories are reviewed regularly. Most are "industrially funded"—competing for funds from sources within and without the Army.

In addition, the mission of the Army Research Office (ARO) is to ". . . develop the Army Materiel Command research program for mathematics, and the physical, engineering, atmospheric, terrestrial, and biological sciences according to Army-wide requirements."[10] Eighty-three percent of the research contract program monies go to universities, 10 percent to industrial laboratories, and 7 percent to Federally Funded Research and Development Centers and not-for-profits.[11] ARO receives guidance from its parent Army Materiel Command, which provides focus to its research programs. ARO has also come to rely on informal types of outside input, especially from the scientists that it supports. The Medical Research and Development Command recently developed an Army Medical Technology Base Plan, which provides guidance to the medical research community within the Army. Finally, the mission of the Army Research Institute for the Behavioral and Social Sciences is to focus on ". . . the acquisition, training, development, utilization and retention of the Army's personnel resources."[12] Three laboratories and many university contracts support this goal.

Navy

Almost all of the 6.1 research dollars in the Navy are disbursed by the Office of Naval Research. Over one-half of ONR funds go to universities, one-fifth to ONR laboratories, over 10 percent to other Navy laboratories, and the final 10 percent to industry and other government research organizations. ONR funding is spread among disciplines, with a little less than one-half devoted to areas of explicit Navy emphasis, such as ocean and atmospheric sciences, computers, and materials. Other areas of support are linked closely to broader defense interests: astronomy and astrophysics; biological, medical, cognitive, and neural sciences; general physics, chemistry, and mathematics; and energy conversion, radiation sciences, and electronics.

In addition to Navy 21, ONR relies on inhouse personnel (including personnel from the ONR laboratories), foreign field offices, and outside experts and panels (including NAS) to help set priorities. This type of planning is relatively new for the Navy. Before 1970, a primary research criterion was the quality of the science. Most of the research was not multidisciplinary and minimal advice was requested from the external scientific community. Now, due in part to the 1970 Mansfield Amendment, mission relevance is a strong criterion; multidisciplinary programs are enhanced and are greater in number; some programs can be put on a "fast-track"; and substantial input is sought from the external scientific community.

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[9] Genevieve J. Knezo, "Defense Basic Research Priorities: Funding and Policy Issues," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Oct. 24, 1990), p. 38.

[10] Army Research Office briefing materials prepared for OTA, May 1990.

[11] Ibid.

[12] Ibid.

Air Force

Before 1974, inhouse Air Force laboratories controlled most 6.1 monies. After 1974, the Air Force consolidated the disbursal of 6.1 monies into one unit, the Air Force Office of Scientific Research. Each laboratory still has a portion of 6.1 monies, but the bulk are distributed by AFOSR. Air Force laboratories compete for these funds along with universities and other performers. In addition to Project Forecast II, each year key personnel in the Air Force research system and managers of the science and technology areas discuss the "macro strategy" for the next year. A report is then sent to the separate parts of the Air Force research system, such as AFOSR, which reinterprets its programs in terms of these goals.

Even though there is a significant amount of "top-down" direction in the distribution of Air Force 6.1 money, it is still primarily a bottom-up process. The influence of top-down management is viewed as adding discipline to the management of research programs, which still respond primarily to scientific community concerns about the direction of research. The balance of top-down and bottom-up management seems intermediate to that in the Army where the management is more decentralized and bottom up, and to the Navy where ONR provides greater top-down management.

DARPA and SDIO

Project selection in research at DARPA is very different from that at other DOD research agencies. Project managers state that they are not attempting to maintain strength across a field, rather they are funding good *ideas* that are on the forefront of technology development to meet desired objectives (see box 4-B).

In the Strategic Defense Initiative Organization, the Innovative Science and Technology Office (ISTO) is the core unit that funds basic and applied research for SDIO. Within the overall mission of developing space surveillance, weapons, and communications technologies, ISTO determines future directions for research. ISTO includes an eight-person research management team, which sets goals and works to see that these goals are achieved. The measure of success is ISTO's impact on SDIO.

At present the three services, SDIO, and DARPA set their own research agendas, gaining the usual advantages of pluralism. In a previous report, OTA also found disadvantages to pluralism, which included "... wasteful duplication of efforts, lack of critical mass to solve common problems, fractionated efforts, and inattention to areas that are on no component's agenda. It also risks failing to identify areas of common or overarching significance."[13] In a mission-oriented organization like DOD, these disadvantages seem too large to ignore. OTA also found previously that the inability to define the products of research has limited DOD's use of quantitative decision support and evaluation methods like those used in industry.[14]

From 1989 to 1990, DOD prepared for a downturn in funding. After a period of phenomenal growth in the 1980s, DOD projected that such funding could not continue, and that a real decline in funds was therefore likely. DOD set in motion planning activities to construct useful options in such a funding scenario, such as the consolidation of several research laboratories, and many of the priorities embodied in these plans have been implemented in the DOD budget. The consequences of these decisions have yet to be evaluated.

National Aeronautics and Space Administration

NASA is now the third largest source of research funds (both basic and applied) in the Federal Government. NASA was created in 1958, 1 year after the launch of Sputnik, and took over the National Advisory Committee on Aeronautics' laboratories. In fiscal year 1960, the research budget was slightly over $0.5 billion (in constant 1982

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[13] Office of Technology Assessment, op. cit., footnote 7.

[14] U.S. Congress, Office of Technology Assessment, "Evaluating Defense Department Research," background paper of the International Security and Commerce Program, June 1990.

Box 4-B—The Defense Advanced Research Projects Agency

Because the creation of new technologies is often interdisciplinary and involves risky research ventures, President Eisenhower felt that ". . . a different type of organization was needed with unique business practices."[1] The mission of the Defense Advanced Research Projects Agency (DARPA), created in 1958, is to ". . . develop 'revolutionary' technologies that can make a significant impact on the future of the United States' defense posture, and to ensure that those technologies effectively enter the appropriate forces and supporting industry base."[2]

The "unique business practices" that now prevail at DARPA involve program managers directly with the projects that they fund and manage. Managers typically create a portfolio of research projects seeking particular objectives, such as the use of Gallium-Arsenide in new micro circuitry developments, and follow them closely. Programs are expected to last 3 to 5 years; the manager is given almost total discretion over funding allocation; and the success of the manager and the program are judged by the results produced.

Managers are also given discretionary money to pursue ideas for future programs, and every year new programs compete for funding. DARPA stresses that this competition is based almost exclusively on the worthiness of a particular idea, not on external considerations such as maintaining U.S. strength in a particular research field. Also, DARPA's contribution must be unique. An "inhouse rule" stresses that 80 percent of the funding in a particular research area must come from DARPA. This targets DARPA's investment in emerging research topics.

DARPA further stresses the importance of allocating enough funds for a project to see it through to completion. Because of funding shifts, many agencies must compromise their programs and projects by allowing only partial funding. At DARPA, programs and projects are routinely terminated to make way for others.

Among the agencies where OTA conducted interviews, DARPA is applauded as the only organization that can effectively trade off agency programs and, if needed, stop a project. DARPA allows less than 1 year to switch program direction, whereas research managers in many other agencies state that it takes at least 2 years, and often much longer, to achieve such redirection. DARPA relies foremost on program managers to determine when to halt a program, which is hailed as a key to DARPA's success.[3]

DARPA's accomplishments in high-performance computing, solid state devices, advanced materials, and many other areas have sparked much congressional interest. Attempts to model other agencies after DARPA, particularly a "Civilian Advanced Research Projects Agency," have concentrated on DARPA's novel organizational style.[4] Congress could also consider instructing the Federal research agencies that do not already have programs specializing in high-risk research to adopt select DARPA management techniques.

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[1] Craig I. Fields, testimony at bearings before the House Committee on Armed Services, Subcommittee on Research and Development, Mar. 1, 1990, p. 1. Also see "The Government's Guiding Hand: An Interview With Ex-DARPA Director Craig Fields," *Technology Review*, February-March 1991, pp. 33-40.

[2] Ibid., p. 1.

[3] See Ted Agres, "DARPA Bets on High-Risk R&D," *Research & Development*, November 1989, pp. 39-42.

[4] See Senate and House bills: S. 1978 and H. 3833; and Senate Committee on Government Affairs, hearing on S. 1978, Trade Technology and Promotion Act of 1989, June 12, 1990.

dollars) and, by fiscal year 1990, it had surpassed $2 billion (in constant 1982 dollars, see again figure 4-1).

Not unexpectedly, the primary focus of NASA research from 1961 to 1969 was directed at achieving President Kennedy's announced goal of landing men safely on the Moon by the end of the decade. The use of satellites for communications, meteorological observations and research, and Earth resource surveys were also persistent emphases. The investment in space was justified on the basis of perceptions of U.S. leadership in science, technology, and world affairs, and of expanding knowledge of the universe. As the economy tightened and the lunar landing neared, the ostensible practical benefits of space research and of space-related technology received increasing emphasis. The end of the Apollo program produced a need for new priorities both to guide the agency's activities and justify continued high levels of funding. In the mid-1970s, the Space Shuttle began to move to center stage.

During the 1980s, research priorities at NASA diversified. NASA began to emphasize commercial uses of space (including industrial research), as well

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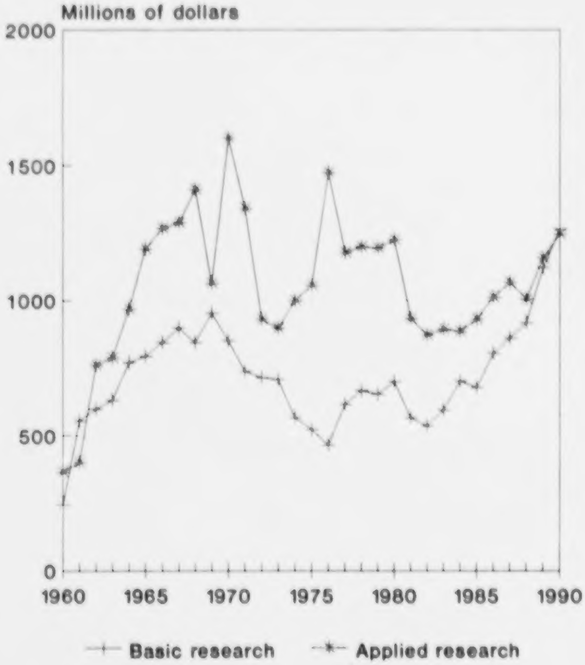
Photo credit: National Aeronautics and Space Administration

Scientists work on a mirror for the Hubble Space Telescope (HST). Building the apparatus for any mission in space, such as the HST, is complex and involves many different components.

as the use of space for defense. In addition, NASA initiated work on the Earth Observing System to collect much more environmental data than had previously been collected from space. Recently, President Bush has also set a goal to return humans to the Moon and explore Mars.

Figure 4-5—Basic and Applied Research Funds at NASA: Fiscal Years 1960-90 (in millions of 1982 dollars)



KEY: NASA = National Aeronautics and Space Administration.

NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

Basic and applied research management at NASA is split between the Office of Space Science and Applications (OSSA) and the Office of Aeronautics, Exploration, and Technology (OAET). Data on basic and applied research funding at NASA are presented in figure 4-5.[15] Over the last three decades, basic research funding has oscillated slowly, between $600 and $800 million (in constant 1982 dollars). Applied research shows a more active history, ranging from $0.8 to $1.6 billion (in constant 1982 dollars), but in the 1980s applied research has held fairly constant at nearly $1.0 billion.

OSSA sets priorities in conjunction with the budget process and by selecting specific projects. The process is essentially bottom up with project managers proposing new initiatives. However, when large missions are proposed, such as Space Station Freedom, top-down direction will determine the parameters of the effort. OSSA recently produced its first strategic plan, which emphasized a commitment to the Space Station Freedom and the Earth Observing System and to flying a mixture of small and large missions.

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[15] OTA notes that many agencies do not find the division into basic, applied, and development useful. Consequently, agency budget offices believe that the data that they report to the National Science Foundation (NSF) is artificial and prone to errors. The NSF figures also remove the funds for equipment purchase from the research and development (R&D) budget line items and add the support funds from the Research and Program Management appropriation associated with R&D. OTA uses these data only as a general indicator of level of effort in particular areas.

The National Research Council (NRC) plays a particularly strong advisory role for OSSA, and the Space Studies Board provides input for most NASA basic research programs. The board is unique at NRC because it has an *institutional* relationship with NASA, i.e., NASA funds the board and requests many studies, but the board can use these resources to initiate studies independently. In fact, the board has been able to preserve its credibility because it has not always agreed with NASA, and has openly disputed it on some occasions. Roughly every 10 years if events do not call for an earlier revision, the board writes a strategic plan for every discipline in OSSA. The Space Studies Board also conducts periodic reviews of the programs and every new mission, and other larger topics such as ''manned'' v. ''unmanned'' flight are routinely studied.

In addition, OSSA has an internal structure of advisory panels. The panels are usually made up of representatives from academia, industry, Federal laboratories, and other interested groups such as program managers from other agencies. They are consulted at least once or twice each year (sometime quarterly) about future directions for research programs. However, as with NRC, their findings are never binding.

In early 1990, ''exploration'' was added to the Office of Aeronautics, Exploration, and Technology, formerly the Office of Aeronautics and Space Technology. The new program participates fully in the Administrator's Moon/Mars Initiative, which gives it a new and higher profile within the agency.

The aeronautics work in OAET is almost all basic and applied research, and OAET views its role as the basic research provider in aeronautics for the country. Consequently OAET's advisory committees are primarily composed of and almost always chaired by industry representatives. Generally the decisions of research direction are made by the associate administrator. It is a somewhat open process, in which there is ample chance for those outside NASA to comment.

In the 1970s and into the 1980s, OAET's space technology component asked of project directors: ''what will they need for the future?'' In 1986 and 1987, the program changed its philosophy. It focused on short-term problems and attempted to promise system delivery by specific dates. In 1989, the deputy administrator questioned this approach. Now 60 percent of the funding goes to near-term solutions to mission problems; 30 percent to long-term solutions; and 10 percent to high-risk research. The first 90 percent is developed in conjunction with mission managers, and the rest is decided within the space technology group, and can be used to support risky research, such as studies on ''wormholes''—shortcuts between distant points in space.

Recent problems have plagued many NASA programs, such as a flaw discovered in the Hubble Space Telescope, the halt of space shuttle flights due to hydrogen leaks, and nagging questions about the Space Station. A reflective look at NASA programs by Congress has been urged, and calls for an overhaul of NASA's management structure have grown louder.[16] Director Truly has cited the need for a better match between agency programs and its resources. In addition, many have pointed to the failure of NASA programs to encourage a civilian space industry that also supports research. While NASA has been charged (since 1960) to promote a civilian space capability, it has been successful to a lesser extent than predicted one, two, and three decades ago.[17] An Advisory Committee on the Future of the U.S. Space Program has reviewed NASA's programs and has suggested such goals as building a reliable space transport system, improving NASA's civilian pay structure, and augmenting

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[16] For example, see David C. Morrison, ''Hill to NASA: Come Down,'' *National Journal*, vol. 22, No. 18, May 5, 1990, pp. 1077-1081; Kathy Sawyer, ''Truly: NASA Needs More Flexibility,'' *The Washington Post*, Sept. 14, 1990, p. A17; and Kathy Sawyer, ''NASA: Mission Implausible,'' *The Washington Post*, Nov. 4, 1990, p. C3.

[17] See Mark R. Oderman, ''A Viewpoint on Commercial Space Activities: Realities and Options for the 1990s,'' *Science, Technology, and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), pp. 253-264.

NASA facilities.[18] OMB and the National Space Council have been directed to create an implementation plan based on its suggestions.[19]

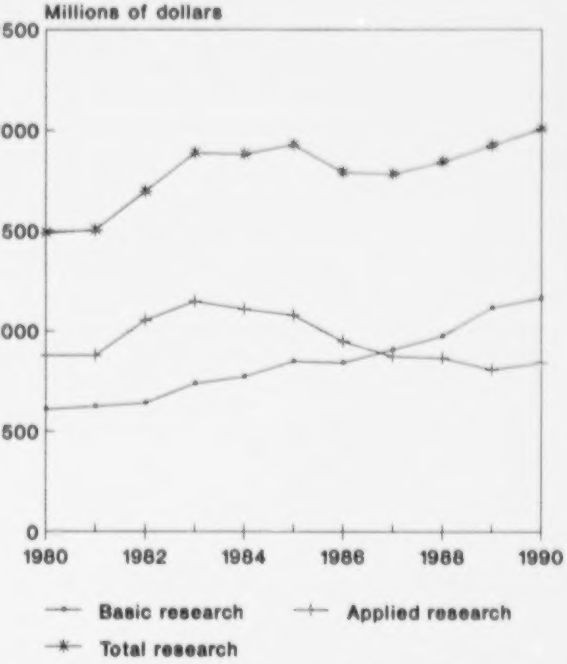
Department of Energy

DOE is the fourth largest source of basic and applied research funds in the Federal Government. DOE is also the youngest of the six major research agencies. Created by the Carter Administration to succeed the Energy Research and Development Administration, DOE inherited a strong research base from another predecessor, the Atomic Energy Commission, including the national laboratories and a network of university researchers.

When DOE was founded, in the wake of the formation of OPEC and the subsequent Arab oil embargo, its top priority was to lessen U.S. dependency on foreign countries for meeting its energy needs. At the same time, rising concern with environmental issues such as water and air pollution spurred research on developing cleaner, more efficient energy sources. Nuclear power was an avenue frequently stressed, although the accident at Three Mile Island in 1979, compounded by cost concerns, seemed to slow work on fast-breeder reactors. The Carter Administration also placed particular emphasis on achieving short-term results through work on conservation, cleaner burning coal, solar electrical power, and other sources.

The 1980s saw a marked shift in the priorities of DOE, emphasizing long-term rather than short-term research and stressing the role of the Federal Government as a risk-taker, pursuing research projects that, if potentially profitable, are to be turned over to the private sector for demonstration and commercial development. The Reagan Administration emphasized basic research over applied research, cutting the latter in the mid-1980s while increasing basic research markedly over the same period (see figure 4-6).

Figure 4-6—Basic and Applied Research at the Department of Energy: Fiscal Years 1980-90 (in millions of 1982 dollars)



NOTE: Figures were converted into constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), tables 4 and 5.

In general, priority-setting mechanisms for research at DOE appear to be very much like those at DOD and NASA in the 1960s.[20] However, compared with other agencies, less accountability is required from project to project. This is not to say that accountability does not exist. DOE is responsive to the scientific community and to the rest of the government. Research managers outside of DOE envy DOE's flexibility, but see the tradeoff as a loss of excitement in working toward a defined goal.

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[18] See Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program* (Washington, DC: U.S. Government Printing Office, December 1990); and Philip C. Abelson, "Future of the U.S. Space Program," *Science*, vol. 251, Feb. 25, 1991, p. 357.

[19] Gene Koprowski, "OMB to Join Summit on Space Report," *Washington Technology*, vol. 5, Dec. 20, 1990, p. 1.

[20] In the defense programs, although nuclear weapons research occurs within both the Department of Energy (DOE) and the Department of Defense (DOD), there is a clear division of labor. DOD builds the delivery systems and DOE produces the nuclear weapons to go inside them. To set goals, every 2 years a document comes from the Pentagon called "Nuclear Weapons Development Guidance." It outlines the requirements of future systems. Based on this document, supplemented with threat assessments and other analyses, the DOE defense group decides the future direction of their research programs. Generally no large redirection is required.

They wonder, too, about DOE's accountability to basic and applied research missions.[21]

Recently, the Secretary of Energy attempted to institute more strategic planning within DOE. In particular, he created a National Energy Strategy (NES) with input from the offices within DOE and from external advisors. The planning process for the NES required planning at all levels of DOE, and Secretary Watkins has sought to maintain and further this planning function at DOE. As it is too early to observe the changes in response to these initiatives, OTA cannot judge their effectiveness, but such planning is reportedly beneficial at other agencies.

In the Office of Energy Research, programs such as Basic Energy Sciences and High Energy and Nuclear Physics use an "iterative" process of priority setting—where ideas are proposed (with origins both within and without DOE), feedback from the scientific community and other parts of government are received, and the proposal is revised—to determine goals. In particular, as national goals are defined and new ideas arise from either within DOE or without, the program will first consider them internally. If the new initiative would fit into the existing program or complement it, then the idea will be fielded to a wider audience. Sometimes this audience includes only other parts of the agency. DOE may, however, hold public workshops and/or panel meetings to devise a plan of action.

If a plan is codified by the Office of Energy Research (OER) or within one division, it is sent out for review to DOE personnel, academic and industrial representatives, and other interested parties. This method of fielding new ideas requires much responsiveness on the part of DOE to groups outside of the agency, including the scientific and industrial communities. This method also develops strong working relationships with these communities, but it can have its drawbacks. For instance, some managers complain that the scientific community tries to dictate on occasion (and more than at other agencies) plans that could never gain either the finances or the political support necessary to emerge as new programs.

Photo credit: U.S. Department of Energy

Researcher at Oak Ridge National Laboratory studies the health and environmental effects resulting from synthetic fuels conversion processes. The Department of Energy sponsors research in many broad scientific areas.

Complicating decisions on priorities is the fact that DOE has a very broad research base. For example, under OER, the Basic Energy Sciences program considers its mission similar to NSF. As one manager put it: ". . . the research that we support is as broad as NSF's, but with a different emphasis." Also, with the major cuts in applied energy research funding during the Reagan Administration, the applied programs in offices outside of OER lost much of their research function. They now may look to OER to develop needed research programs.

In addition, each program has an advisory panel, such as the High Energy Physics Advisory Panel. Until recently there was also an overall advisory committee, the Energy Research Advisory Board (ERAB), which reported to the Director of Energy Research and the Secretary of Energy. This group was disbanded in early 1990, and the Secretary has formed the Secretary of Energy's Advisory Board (SEAB), which is already in operation. SEAB's charter has been expanded beyond the scope of ERAB, to include advice on the National Energy Strategy and on the role of the national laboratories.

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[21] Consider for example, the Department's ambivalence over and checkered funding history of the fusion research program. Fusion is seen by many as the best long-term alternative to fossil fuel energy dependence. U.S. participation in a major multinational effort to design a fusion energy test reactor, the International Thermonuclear Experimental Reactor, marks a renewed commitment that is reflected in the Administration's fiscal year 1991 budget. See Mark Crawford, "U.S. Backing for Fusion Project Seen," *Science*, vol. 251, Jan. 25, 1991, p. 371; and Christopher Anderson, "DOE Rallies to Save U.S. Fusion Research Program," *Nature*, vol. 349, Jan. 24, 1991, p. 269.

In the late 1970s and early 1980s, while the Reagan Administration was entertaining notions of abolishing DOE, many interviewees said that the planning for DOE's research was more external to the agency, with NAS and other organizations playing key roles. Program shifts were primarily budget controlled and long-term goals often suffered. Furthermore, many decisions on specific programs were dictated by the scientific community they served. The interviewees state further that the system has now evolved so that DOE can make decisions that balance external as well as internal forces. This is accomplished primarily through the iterative process described above. Differences between programs are due primarily to the constituencies and the types of problems addressed, but differences are also due to historical tradition.

In the applied research offices of DOE, processes of goal setting are also iterative. Most ideas are first taken up internally, and then may be augmented by contractor reports. After much deliberation, they are taken to the public. Five-year plans are written for all new programs and receive extensive review.

In the late 1970s and early 1980s, the process of priority setting for applied research was inward looking. Now with the large consulting process described above and participation by industry, DOE perceives that it is better serving its "client"—the energy industry—and thereby the public. During the Reagan Administration, the emphasis was on funding research that was too risky for industry. Under the Bush Administration, the emphasis seems to have shifted toward projects perceived to have the highest payoff for industry and DOE.[22]

National Science Foundation

NSF is the fifth largest source of basic and applied research funds in the Federal Government. Established in 1951, it has evolved into an agency composed of eight directorates in addition to the Director's Office. The Director and Deputy Director are appointed by the President and serve 6-year terms. Five of the directorates fund basic and applied science and engineering; another two focus on education, human resources, data, and policy; and one handles NSF's administrative matters. On average, each directorate has five divisions. Each division has several programs.

The primary role of NSF is to support basic research and science education across broad categories of science and engineering. This is done primarily through support for university-based individual investigators, who absorb over 60 percent of the research budget. Aggregate support to groups and centers represents a small portion of the budget (less than 10 percent) and is more sensitive to budget fluctuations.[23] Support for individual investigators is considered the primary mission, even by those managers with portfolios covering group and center support.

A number of research administrators at NSF prefer to use the terminology "fundamental v. directed" rather than "basic v. applied" in making distinctions between categories of research funding.[24] In using the former terminology, they are likely to respond that they fund both (but much more fundamental than directed). In using the latter terminology, they are more likely to say they fund only basic research. Most administrators say that they never give a grant with applications in mind, but they are pleased when grantees cite NSF-funded work when seeking patent applications.

In its first operating year, the NSF budget was $151,000. In constant dollars, the budget has grown over NSF's history, although not consistently (see table 4-2). The NSF budget authority for fiscal year 1991 is $2.2 billion. Currently, NSF funding is provided in six separate appropriations: Research and Related Activities (R&RA); Education and Human Resources (EHR, formerly Science and Engineering Education); U.S. Antarctic Program; Facilities, Program Development and Management; and the Office of Inspector General. R&RA has

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[22] For example, see Alan Schriesheim, "Toward a Golden Age for Technology Transfer," *Issues in Science & Technology*, vol. 7, winter 1990-91, pp. 52-58.

[23] National Science Foundation, *Report on Funding Trends and Balance of Activities: National Science Foundation 1951-1988*, special report, NSF 88-3 (Washington, DC: 1988).

[24] OTA interviews at the National Science Foundation, spring 1990.

Table 4-2—National Science Foundation Obligations: Fiscal Years 1952-90
(In millions of constant 1982 dollars)

Year	Total obligations	Research and related activities
1952	$ 13.6	$ 7.6
1954	28.6	23.1
1956	54.8	44.4
1958	159.7	102.1
1960	494.1	287.0
1962	795.2	548.8
1964	1,049.1	724.3
1966	1,316.5	942.7
1968	1,319.2	942.0
1970	1,100.2	783.6
1972	1,292.9	1,032.2
1974	1,195.7	1,000.4
1976	1,148.1	972.0
1978	1,187.3	1,017.9
1980	1,138.8	983.6
1982	999.1	909.7
1984	1,213.4	1,065.0
1986	1,311.9	1,140.0
1988	1,420.1	1,202.2
1990	1,586.7	1,312.9

NOTE: Fiscal year 1990 figures are estimates.

SOURCE: National Science Foundation, *Report on Funding Trends and Balance of Activities: National Science Foundation, 1951-1988*, special report, NSF 88-3 (Washington DC: 1988); and National Science Foundation, press release, PR 90-05, Jan. 29, 1990.

accounted for more than 70 percent of the budget since 1967, and 80 percent or more since 1982. EHR has been the most variable, ranging from 46 percent in 1959 to a low of 1.5 percent in 1983. It is also the target of recent increases, approaching an all-time high of $322 million of NSF's $2.2 billion fiscal year 1991 budget.

Within directorates, research funding is very much a bottom-up process. Goals are set by scientific opportunity and the proposal process, as well as in special initiatives from advisory panels. Through its grants program, NSF receives proposals for research spanning the fullest range of science and engineering. The scientific community is NSF's constituency, and program staff project a strong sense of obligation and commitment to that community. There is an explicit ethic pervading the directorates that discourages heavy-handedness in the setting of priorities. Staff serve as interpreters, advocates, and jurors throughout the priority-setting and planning process.

An exception to the above lies in the Engineering Directorate. Created as a separate unit in 1983, Engineering tends to set its priorities around national needs. For example, a recent initiative involved a Request for Proposals in design and manufacturing systems. It was the sense of NSF staff and its advisory committees that there was a need for research in those areas. In addition, the Engineering Directorate tends to address problems more centrally, and many areas of engineering are cross-disciplinary. To this extent, the divisions of Engineering, and the methods by which they set priorities, differ somewhat from the way other directorates operate.

The agency primarily sets priorities and plans through a process described by many as "... continuous, open, and decentralized." The decision cycle is keyed to the annual Federal budget and annual appropriation cycles. Eight populations provide formal and informal input into the planning process. They are: 1) the National Science Board (NSB); 2) advisory committees; 3) professional societies; 4) NRC; 5) Visiting Scientists, Engineers, and Educators (also known as "rotators"); 6) NSF staff; 7) the Inter-Directorate Task Force; and 8) Congress.

Each spring, the advisory committees meet with program managers and division directors to recommend priorities for the current year and years to come. Besides scientific opportunity, staff usually recommend that NSF not fund research already well-supported by other agencies.

Plans are eventually forwarded to NSB for consideration at their June meeting. A strategic plan is developed that must be set against the general recommendations of NSB. For example, in 1989, NSB decided on four general priorities for NSF to pursue—international cooperation in research, education, economic competitiveness, and better methods for leveraging Federal dollars (i.e., to share funding with other—typically State or private—sources). If an organizational unit within the agency proposes a new program that covers all or most of these priorities, it has a very good chance of getting a proportional increase in its budget. For example, in the late 1970s it was decided that there should be more funds for the physical sciences in the 1980s; in the 1980s it was decided that in the 1990s NSF should focus on building strength in engineering and computer sciences. The mid- to late 1990s should bring more funds to environmental sciences and geosciences. National needs are very much a part of the planning process.

In addition to planning conducted on a program basis, there has been increasing attention paid to planning on an activity basis: by whom and how will research be conducted? This has resulted in more support for women and minorities and broader geographic distribution of funds. Between 1985 and 1990, support for the individual investigator went up 25 percent as compared to other research funding modes, such as groups and centers.

NSF faces a daunting task—being all things to all people. The organic act entrusts it with the support of the Nation's basic research and science education. (Thus, every research program at NSF has an impact on human resources.[25]) Within the scientific community, however, there is growing concern that NSF has reduced its flexibility by relying too strongly on traditional mechanisms to set priorities and allocate funds. While not wishing to abandon peer review, NSF has sought some alternatives. A recent report, which addresses these issues of emphasis and process from the perspective of senior staff, stresses that NSF must serve all research performers, streamline the proposal process, and better integrate human resources with research funding considerations.[26]

Department of Agriculture

USDA is now the sixth largest source of basic and applied research funds in the Federal Government. USDA has a long history of support for research, especially when compared with other government agencies. In 1862, the Morrill Land-Grant College Act recognized the importance of agricultural research and education by setting aside Federal land for agricultural colleges. In 1887, the Hatch Act created the State Agricultural Experiment Stations and assigned administrative responsibility for them to the land-grant institutions. During this time, USDA also grew in power as a research provider, creating an expanding research network.[27]

In the late 1960s, environmental problems began to dominate discussions of research in agriculture, with particular concern expressed for finding alternatives to the use of chemicals as pesticides and in fighting plant and animal disease. Throughout the last three decades, research on human nutrition has been stressed, as well as with finding means for improving the productivity of American farms.

R&D funding levels for USDA since 1955 are tabulated with the other agencies in table 4-3. In constant dollars, USDA R&D funds have hardly grown since 1965. For basic and applied research, the figures are similar. In 1960, USDA research funds totaled just under $0.5 billion. Throughout the 1960s, 1970s, and 1980s, their total grew steadily, but declined from 1985 to slightly under $0.8 billion in fiscal year 1988.

USDA is advised by many groups. Most important is the Joint Council on Food and Agricultural Sciences (JCFAS), created by an act of Congress in 1977 to coordinate and encourage research, extension, and higher education in agriculture. Its members include influential representatives from public and private sectors, producers, industry, and government; as well as directors of research, extension, and higher education activities in universities, agricultural experiment stations, and other centers. While JCFAS has the mandate to evaluate and recommend changes to USDA programs, it cannot direct USDA to institute them. Another advisory body is the Users Advisory Board on Research and Education, with membership selected from those who benefit from research and education. These and other groups advise the various research components of USDA.

Agricultural Research Service (ARS)

ARS was established in 1953 as USDA's inhouse agricultural research agency.[28] The National Program Staff (NPS) is a core component of ARS headquarters and is responsible to the administrator for planning, developing, and coordinating the ARS

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[25] Although the National Science Foundation's (NSF) share of the total Federal research and development budget requested for fiscal year 1992 is only 3 percent, its education and human resources programs represent 23 percent of the total proposed Federal agency effort. Programs such as Research Experiences for Undergraduates (which is slated to support almost 12,000 students) are increasingly visible. See Frederick M. Bernthal, acting director, National Science Foundation, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Science, Feb. 20, 1991, pp. 7-8, 11.

[26] See National Science Foundation, *Report of the Merit Review Task Force*, NSF 90-113 (Washington, DC: Aug. 23, 1990); and Jeffrey Mervis, "Panel Weighs Overhaul of NSF's Grant System," *The Scientist*, vol. 5, No. 1, Jan. 7, 1991, pp. 1, 6-7, 12.

[27] Lawrence Busch and William B. Lacy, *Science, Agriculture, and the Politics of Research* (Boulder, CO: Westview Press, 1983).

[28] Central offices of the Agricultural Research Service (ARS) are in Washington, DC, and Beltsville, MD. There are approximately 7,000 full-time employees (of which 2,350 are scientists) scattered across the United States, Puerto Rico, the Virgin Islands, and several foreign countries. Research is conducted at 122 domestic and 6 overseas locations by civil service scientists. Last year there were about 1,700 projects ongoing with budgets ranging from $100,000 to $1 million. Much of the work of ARS is conducted in direct cooperation with the State agricultural experiment stations, other State and Federal agencies, and private organizations.

Table 4-3—Trends in Federal Obligations for Total Research and Development, by Major Agency: Fiscal Years 1955-88 (in millions of constant 1982 dollars)

Year	USDA	HHS	NSF	DOE	NASA	All other agencies	Total nondefense agencies	DOD
1955	$347	$ 327	$ 46	$1,574	$ 207	$ 325	$ 2,586	$ 9,591
1960	505	1,284	300	3,059	1,483	759	7,390	22,938
1965	788	3,050	657	4,353	17,374	1,156	27,525	23,753
1970	738	3,205	758	3,533	9,974	2,410	20,941	19,319
1975	728	4,155	1,031	3,548	5,311	2,603	17,376	15,620
1980	804	4,421	1,031	5,560	3,783	2,938	18,357	16,352
1985	837	4,865	1,195	4,410	2,955	2,227	16,490	26,458
1988	778	5,079	1,379	4,027	3,636	1,862	16,761	34,489
Agency Percentage of Total Annual Nondefense R&D Funding								
1955	13.4	12.6	1.8	60.9	8.0	12.6	100	
1960	6.8	17.4	4.1	41.4	20.1	10.3	100	
1965	2.9	11.1	2.4	15.8	63.1	4.2	100	
1970	3.5	15.3	3.6	16.9	47.6	11.5	100	
1975	4.2	23.9	5.9	20.4	30.6	15.0	100	
1980	4.4	24.1	5.6	30.3	20.6	16.0	100	
1985	5.1	29.5	7.2	26.7	17.9	13.5	100	
1988	4.6	30.3	8.2	24.0	21.7	11.1	100	

KEY: USDA=U.S. Department of Agriculture; HHS=U.S. Department of Health and Human Services; NSF=National Science Foundation; DOE=U.S. Department of Energy; NASA=National Aeronautics and Space Administration; DOD=U.S. Department of Defense.

NOTE: Totals are not exact due to rounding.

SOURCE: National Research Council, *Investing in Research: A Proposal to Strengthen the Agricultural, Food, and Environmental System* (Washington, DC: National Academy Press, 1989), table A.1, p. 96.

national research program. There are about 30 NPS employees with expertise in a discipline, commodity, or problem. Their role is individually and collectively to plan research programs, set priorities, allocate resources, review and evaluate research progress, and provide coordination.

ARS has a long-range Program Plan—designed in the 1980s—and an Implementation Plan, which describe how the Program Plan is to be operated over a 6-year period. The Program Plan focuses on the goals, objectives, and broad research approaches that ARS will pursue. The current Implementation Plan covers 1986 through 1992 and considers, among other things, how the budget and shifts in research needs relate to the goals and mission of the agency. This strategic planning is relatively new, having started in 1983. Administrators of NPS feel that the development of the Implementation Plan has enabled them to set priorities, helped in redirection of funds, and has increased communication between ARS and groups such as other USDA agencies, Congress, user groups, and scientists.

The Implementation Plan was put together by NPS and the ARS laboratories with input from industry, academia, and regulatory agencies. Because program areas often overlap, NPS works together in planning for the entire research program. NPS, therefore, is very centralized and not only does planning and priority setting, but also makes allocation decisions and performs program reviews.

Cooperative State Research Service (CSRS)

CSRS is USDA's "... principal entree into the university system of the United States for the purpose of conducting agricultural research." It "... participates in a nationwide system of agricultural research program planning and coordination among the State institutions, USDA, and the agricultural industry of America."[29] Programs of research are jointly developed with the State Agricultural Experiment Stations, forestry schools, 1890 Land-Grant Universities, and other cooperating institutions. The most recent planning exercise resulted in the strategic plan entitled "A Research Agenda for the 1990s." This is the first time that such a strategic plan has been developed. It outlines current research efforts and areas of proposed enhancement, including the safety and stability of consumer foods, and the protection of water quality.

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[29] Cooperative State Research Service, "Budget Submission for 1990," hearing before the House Subcommittee on Rural Development, Agriculture, and Related Agencies Appropriations of the Committee on Appropriations, Part 2, p. 444, 1989.

Photo credit: U.S. Department of Agriculture

An Agricultural Research Service scientist (rear) and a graduate student (front) transplant seedless grape varieties. Research and education are intertwined in many research areas.

The majority of CSRS Federal funds (approximately $200 million out of the $340 million in fiscal year 1989) comprise *formula funds*, which are directly appropriated by specific acts of Congress. *Special Research Grants* amount to another $61 million (fiscal year 1989), and consist mostly of line item appropriations (which many liken to earmarks) requiring oversight from CSRS. Priority setting is negotiated between the cooperating institutions and CSRS. In addition, the *Competitive Research Grants Office* (CRGO) conducts a nationwide competition for basic research funds in specific fields. CRGO began in 1978 with programs in plant science and nutrition and, by 1985, it had expanded to include animal and biotechnology research. NRC, with strong support from USDA, has proposed a National Agriculture Research Initiative, which would enlarge the USDA Grants Program from $45 million to over $500 million. The program would increase research funds in areas not presently supported at USDA, such as global climate change.[30]

Forest Service

The research mission of the Forest Service is to "... serve society by developing and communicating scientific information and technology needed to protect, manage, and use the renewable natural resources of the Nation's 1.6 billion acres of forest and related range lands."[31] Within the structure of USDA, the Forest Service is quite separate from CSRS and ARS, as it reports to the Office of the Assistant Secretary for Natural Resources and Environment rather than the Assistant Secretary for Science and Education. Furthermore, its budget is not considered by the congressional agriculture committees in Congress, but by the interior committees.[32]

The decentralized nature of the Forest Service research work force encourages bottom-up planning.[33] Recently the Forest Service stations have been required to submit budgets at four different funding levels, ranging from 90 percent of the funding level 2 years before to 10 percent over the agency request from the prior year. An iterative process between Washington and the stations adjusts what work will be done at different budget levels. Perhaps the most important trend is that in the early 1980s, and before, the budget process was tightly controlled by the Deputy Chief for Forestry Research. Now the process is much more open, and the stations are more responsive to national problems, such as global change, water quality, and endangered species. For instance, the percentage of funding devoted to national problems rose from 28 percent in fiscal year 1989 to 42 percent in the fiscal year 1991 Presidential request, with new developments funded as special initiatives.

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[30] See U.S. Department of Agriculture, Cooperative State Research Service, *National Research Initiative Competitive Grants Program: Program Description* (Washington, DC: 1990).

[31] See U.S. Department of Agriculture, "Strategy for the '90s for USDA Forest Service Research," review copy, February 1990.

[32] The Forest Service has eight regional Research Stations and the Forest Products Laboratory (FPL) where research is conducted. Within the 8 stations and FPL, 190 Research Work Units (RWUs) are gathered at 74 locations. Over 700 scientists work in these units with a total budget of nearly $150 million. Extramural research is supported at a low level—approximately $14 million per year, although this is deceptive since many of the RWUs are located on college campuses.

[33] In practice, Research Work Unit Descriptions (RWUDs) charter work in a particular problem area. They usually prescribe a plan for a 5-year duration and often will build directly on previous work. The Station Director has a large amount of discretion to choose projects at the RWU level, and the RWUDs are reviewed inhouse in the Washington Office to provide balance in a nationally coordinated program.

OTA found in this and earlier studies that investment in research at USDA has lagged behind other agencies, and that USDA has difficulty in clearly stating its mission, planning for the future, or setting priorities in research.[34] Consequently, much of the new agriculture-related science (e.g., biotechnology) is performed by scientists who are not trained in the agricultural sciences and who do not pursue agricultural problems. Many blame the lack of growth in research funding at the agency to the lack of a comprehensive strategic plan.[35]

Other Agencies

The six agencies described above together devote over $11 billion annually to basic research. Also contributing to the research base, but on a much smaller scale, are the following 10 agencies: the Alcohol, Drug Abuse, and Mental Health Administration (in HHS); the U.S. Geological Survey (in the Department of the Interior); the Smithsonian Institution; the Environmental Protection Agency; the National Institute of Standards and Technology and the National Oceanic and Atmospheric Administration (both in the Department of Commerce); the Department of Veterans Affairs; the Department of Education; the Agency for International Development (in the Department of State); and the Department of Transportation. This group of 10 agencies represents approximately 5 percent of the total Federal expenditure on basic research.[36] Although their contribution is comparatively small, these agencies lend breadth and flexibility to the Nation's research capacity.

Crosscutting Descriptions of Agency Priority Setting

Comparisons of the research agencies reveal the variation and complexity in the Federal research system. While agency cultures are very different, the prospect of transferring methods and standards across agency boundaries deserves consideration. OTA first examines various characteristics of the organization and management of the Federal research system.

Division of Labor

The Federal research system can be thought of as a composite of the various agencies that support research. Each agency has a mission and therefore a purview of research responsibility. NSF and NIH, for example, have the broadest scope in research areas funded. Any project within a discipline that is of high quality and does not clearly fall under any other agency's jurisdiction can be a candidate for funds.[37]

NASA, DOE, DOD, and USDA have more restrictions (than NIH or NSF) on the research areas that they support. NASA supports science that can make use of space (and most often seeks information about space), either through satellites, experiments above the atmosphere, or human exposure to zero gravity. DOE funds research relating to nuclear weapons and all forms of energy and its effects on humans and the environment, which is interpreted broadly in the Department.

Although some claim that because the research areas supported by DOD and USDA are closely tied to their technical missions, the research by definition cannot be basic or fundamental in nature. Indeed, OTA finds that the research supported by these agencies can be as fundamental as that supported by other agencies, such as NIH or NSF. In addition, the amount of funds spent on basic research at these agencies is comparable in size to that disbursed by NSF. Nonetheless, these agencies' priorities shape research goals.

Areas of support among the agencies allow a multitude of questions to be posed and investigated differently within the research system. This also provides some measure of pluralism in research opportunities, i.e., many researchers have two or three agencies (and even more programs) within the

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[34] U.S. Congress, Office of Technology Assessment, *Agricultural Research and Technology Transfer Policies for the 1990s*, special report, OTA-F-448 (Washington, DC: U.S. Government Printing Office, March 1990).

[35] Ibid.

[36] All budget data reported below are based on National Science Foundation, Division of Science Resources Studies, *Federal Funds for Research and Development: Detailed Historical Tables, Fiscal Years 1955-1990* (Washington, DC: 1990); and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990, and 1991* (Washington, DC: December 1990).

[37] Researchers quickly learn what research is and is not eligible for funding at an agency. Program announcements, conversations with program officers, and the fate of other submitted proposals convey to the researcher which agency (and program within it) is an appropriate source of funding. This, too, is part of the agency culture, which forms a constituency of extramural research performers.

Federal Government to apply for funds. Pluralism has long been hailed by the scientific community as a strength of the research system in the United States.[38] However, the pursuit of agency missions is not without legislative contention, as Congress consistently asks agency managers, in authorization and appropriations hearings, how specific research programs support the agency mission.[39]

Coordination

The division of labor among the agencies does not seek to eliminate overlap; indeed, agencies cooperate to fund some areas of mutual interest. Agencies with broad research agendas, such as NSF and NIH, coordinate more routinely with other agencies—more than those, such as USDA, with a more narrow scope.

In addition, because of the size of agencies and departments, coordination *within* the agency or department can be important as well. For example, the services in DOD sometimes attempt to find a niche in a scientific area so there is no overlap with another service. In supercomputers or artificial intelligence, for instance, the Air Force has chosen to rely on the other services. The Air Force in turn takes the lead in other areas, such as mathematical control theory. In areas that require overlap, however, agencywide committees are often employed to coordinate the activities of the services, DARPA, and SDIO.[40]

Coordination among and within Federal agencies occurs at two levels, at the agency program level and at the research performer level. Agency-level coordination generally occurs through committees. One standing coordinating mechanism is the Federal Coordinating Council on Science, Engineering, and Technology in the Office of Science and Technology Policy. It has several subcommittees, such as Global Change and High-Performance Computing, which provide a forum in which agencies can communicate (see chapter 5). Other committees that are not governmentwide also exist, which may coordinate two or more agencies on a specific topic.

Researcher and program manager level coordination occurs through meetings and other communication that is a normal part of the discourse of the scientific community. It is at this level that the separate roles of agencies are most apparent and that researchers accommodate to changing funding levels in the cooperating agencies. An illustration of agency and performer interaction can be found in superconductivity research (see box 4-C).

Bottom-Up and Top-Down Management, and the Use of External Advice

One of the most prevalent styles of management of research has been loosely titled bottom up, which implies that research ideas and priorities originate with researchers who communicate these ideas to their sponsors (agency program managers, for example). These managers in turn talk to their superiors. As ideas percolate, their relative importance is set. Bottom-up management contrasts with top-down management, where the most senior decisionmakers in an agency decide the priorities for the system, or their part of it. These directives are then transmitted down the organizational ladder in consultation with managers, eventually to researchers.

OTA finds that in the research agencies both kinds of management are prevalent and are often mixed. In short, decisionmaking is more complicated. Some agencies employ much stronger top-down direction. In the Agricultural Research Service of USDA, priorities are set by the National Program Staff, and at DOD, managers at all levels exert a great deal of influence over the areas in which they support projects. On the other hand, agencies such as NSF and NIH employ mostly bottom-up management. At NSF, this means that only priorities among areas of support are set at the top (by the Director, the Assistant Directors, and NSB). For example, deci-

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[38] As Hunter Dupree observed: "A plural set of government agencies went to a plural set of congressional committees to ask for appropriations, which were then distributed by grant and contract to investigators in a plural set of universities." Quoted in U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, *A History of Science Policy in the United States, 1940-1985*, 99th Cong. (Washington, DC: U.S. Government Printing Office, September 1986), p. 40.

[39] Overlap in support responsibility among agencies for certain areas of research ensures better diffusion of results into multiple applications, a kind of inadvertent diffusion policy. Harvey Brooks, Harvard University, personal communication, February 1991.

[40] A very good example is the Joint Services Electronics Program, operated continuously since 1945, in about 20 or so universities. The three military services provide equal contributions to each university group, but delegate administration to one service. For example, Harvard University and the Massachusetts Institute of Technology each have such a program administered by the Office of Naval Research. This is a fairly successful interdisciplinary program. Ibid.

Box 4-C—Coordination of Superconductivity R&D

Major research initiatives are usually executed by one Federal agency, based on the scope of the research and the mission of that agency. There are exceptions, of course, where research on one area is done in several different agencies, and these research areas bring with them the added burden of coordination. In the case of superconductivity, coordination becomes especially important since research is spread among several different agencies, primarily the Departments of Defense (DOD), Energy (DOE), and Commerce, the National Science Foundation, and the National Aeronautics and Space Administration (NASA).[1]

There are two aspects of coordination that require quite different approaches. First, coordination is required to monitor the different programs and make appropriate decisions to ensure an efficient allocation of research funds to all of the agencies. Second, at the researcher and program level, there must be an adequate flow of information between researchers to avoid overlap or duplication of research. Effective coordination at both the national level and the researcher level is vital to a successful research program.

Congress has made several attempts to encourage coordination of superconductivity research and development by the executive branch. Part of the 1988 Omnibus Trade and Competitiveness Act created the National Commission on Superconductivity (NCS) which was to meet, produce a report, and then dissolve by December 1989. The Trade Act also mandated an increase in staff for the National Critical Materials Council (NCMC), which at the time had no active members. Finally, the National Superconductivity and Competitiveness Act of 1988 called for cooperation between the Office of Science and Technology Policy (OSTP), NCMC, and NCS in order to produce a 5-year National Action Plan for Superconductivity to be accompanied by annual reports.

The success of these initiatives has been limited. The 5-year National Action Plan was published in December of 1989, but the formation of NCS was delayed, so it did not take part in the plan's formation. Although the plan itself acknowledged the need for better Federal coordination, it lacked both the budget recommendations and the long-term perspective Congress had requested.[2] In addition, the Federal Coordinating Council on Science, Engineering, and Technology Committee on Superconductivity report of March 1989 did little more than assemble agency superconductivity budget data and list various programs.[3]

Fortunately, at the researcher and agency program level, the exchange of information has successfully protected superconductivity research from overlap and duplication. Programs at different Federal agencies have aided scientists in the exchange of research information, if not actual coordination of effort. The Ames laboratory distributes the "High-Tc Update," a widely read newsletter; the national laboratories have broadcast nationally several high-temperature superconductivity conferences; and DOE has established a computer database that shares research results with industry. NASA also maintains communication through the Space Systems Technical Advisory Committee, a group with representatives from industry, universities, and government organizations.

The success of the ground-level coordination efforts is promising, but the resistance to priority setting from the administration may inhibit the progress of superconductivity research. In particular, such questions as whether DOD funds too high a percentage of superconductivity research, and whether the Federal laboratories are doing too much of the research relative to other performers are important to the future success of the development of superconductivity. These questions must be addressed through agency-level coordination.

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[1] Funding levels at each agency, of course, are a separate and perhaps more pressing issue. See Kim A. McDonald, "Panel Urges Increased Support for Superconductivity, Recommends Specific Goals for Research in Field," *The Chronicle of Higher Education*, vol. 36, No. 48, Aug. 15, 1990, pp. A5, A7.

[2] U.S. Congress, Office of Technology Assessment, *High-Temperature Superconductivity in Perspective*, OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990), p. 63.

[3] Ibid., p. 69.

sions are made to support the physics program at one funding level and the chemistry program at another. Bottom-up management at NSF and NIH leads to a different selection mentality than that in other agencies, specifically to reliance on peer review as a formal mechanism for incorporating advice from the scientific community.

Agencies that are more bottom up also tend to employ more panels or to commission more studies from outside of the agency to help set priorities. At NSF, NIH, and NASA, standing external committees, NAS, the National Academy of Engineering, and the Institute of Medicine play significant roles in deciding agency priorities. However, agencies

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such as DOE, USDA, and DOD employ outside panels to assist in determining research directions to a lesser extent.

Another difference between top-down and bottom-up management is the degree to which the agency becomes invested in the success or failure of a project. For example, DOD has a large operational investment in the results of the research it supports. This provides an atmosphere that reminds researchers that DOD has a stake in their success. Consequently, these researchers report favorably that DOD is more realistic about the funds and time needed to complete a project, and program managers are more available during the course of the project to aid with difficulties that may arise.[41] This contrasts with the experience of NSF and NIH researchers where the agency does not have a stake in the success of any *one* project, because there is no expectation of direct "use" and no timetable for making "progress."

Intramural and Extramural Research

Five of the agencies that OTA studied support intramural research (NIH, DOE, DOD, NASA, and USDA). Intramural research facilities are most often within laboratories either run directly by the agency or by an outside contractor. Together the Federal research agencies are the primary sponsors of hundreds of laboratories. Some are administered directly by the Federal Government, such as NASA's Goddard Space Flight Center, while others are administered by a university or corporation, such as DOE's national laboratories. Laboratories can be funded *institutionally*, where monies flow from the research agency to support all activities at the laboratory, or *industrially*, where the laboratory competes with other laboratories and research organizations to perform research for clients in number of research agencies. Often there is a mixture between institutional and industrial support within a laboratory, as in many of the DOE national laboratories.

Intramural Research

Research in intramural laboratories has many distinct advantages for the Federal Government. First, laboratories can maintain a research effort over one or more decades. Second, laboratories can easily incorporate a multidisciplinary approach to problems. Third, DOE managers report that they more often fund "risky" research—research that has a very good chance of abject failure, but also a good chance of resounding success—at the laboratories, because the laboratories can absorb a setback without jeopardizing graduate students or young faculty. Fourth, project managers can easily maintain their involvement in the projects at a laboratory. Fifth, the research at the laboratories can be put "on the fast track," in the words of one manager, when the results are needed on a timetable. Sixth, there is ample evidence that the laboratories can often perform research at a reduced cost to that performed extramurally. Finally, the laboratories are often the only sensible place to site facilities needed for a project, because access and maintenance can be assured.[42]

J. ROBERT OPPENHEIMER STUDY CENTER
LOS ALAMOS NATIONAL LABORATORY

Photo credit: U.S. Department of Energy

Los Alamos National Laboratory (LANL) is one of the oldest intramural laboratories of the Department of Energy. LANL was established in 1943 to develop World War II atomic bombs, and today retains responsibility for conducting defense-related research programs. Research at LANL has also diversified into other fields such as fossil and geothermal energy.

Disadvantages of intramural research include problems in recruiting and retaining personnel. The government laboratories must pay on the Federal pay scale, but while salaries have risen in academia and industry for scientists, growth in salaries in the Federal Government has been very slow.[43] Consequently, although research problems addressed at the laboratories and the research environment can be very exciting, researchers are often attracted by much higher paying and more flexible jobs elsewhere.[44] Some critics claim that the pay scale and government cutbacks have limited the quantity and quality of research in the Federal laboratories.[45] In addition, intramural laboratories often do not support graduate students, which are an invigorating part of research.

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[41] This suggests that differences in project monitoring more or less create the need for ex post accountability—and the call for evaluation of project outcomes (see ch. 8).

[42] This also makes laboratories important sites of science education. The role of mission agencies and their laboratories in science education has grown noticeably, especially at the Department of Energy. See U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, *Role of the Department of Energy's National Laboratories in Science, Engineering and Mathematics Education*, 101st Cong. (Washington, DC: U.S. Government Printing Office, June 13, 1990).

Another disadvantage is that many laboratories are large organizations. While they were built with a mission (or a set of missions) in mind, the mission may have been achieved or abandoned.[46] The laboratory must then find a new mission or face the prospect of downsizing or phaseout. Laboratories have sometimes moved from mission to mission, but this can lead to great stress in the organization.[47]

Extramural Research

The advantages of extramural research include competition on the "open market" for the best research teams for a particular problem. (Note that laboratory teams can often compete for these funds as well.) Extramural researchers are paid competitively and can be solicited for one project. The research performers are top scientists in an area and enjoy access to state-of-the-art equipment.

Disadvantages of relying on extramural research are, first, that extramural researchers must bid for the project. If a new project is not associated with enough gain (either in money, equipment, or publications), it is difficult to find extramural researchers willing to apply (although this may also be true in some cases for intramural laboratories).[48] In academia, government-sponsored research is also constrained by the academic environment. For example, although DARPA funds university research, on some projects DARPA finds it difficult to work solely with universities. The university structure of research, with a professor and his or her graduate students, often operates too slowly for DARPA's purposes. Also, DARPA reserves the right to terminate at any point, which can be disastrous for a professor and especially for a graduate student.

OTA finds that both intramural and extramural capabilities are important for the advantages they provide the agencies; both should be supported by the Federal Government.[49] At present roughly one-quarter of all research funds are spent intramurally, slightly under one-half extramurally in universities or colleges, one-quarter in industry, and one-twentieth by other performers.[50]

Issues of Agency Priority Setting

Some priority-setting issues are of particular concern across all of the research agencies. OTA identifies four in particular: 1) risk-taking and conservatism, 2) flexibility, 3) strategic planning, and 4) redirecting the agencies.

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[43] U.S. Department of Commerce, Bureau of Economic Analysis Government Division, "Biomedical Research and Development Price Index," report to the National Institutes of Health, Mar. 30, 1990.

[44] Pepper Leeper, "NIH Intramural Program: No Radical Changes Needed," *NewsReport of the National Research Council*, December 1988-January 1989, pp. 2-5.

[45] For example, see Knezo, op. cit., footnote 9, p. 38. Similar statements were made in several OTA interviews at the research agencies.

[46] "Also, big labs tend to become bureaucratized as Federal pay policy leads to a gerontocracy, with the least entrepreneurial people staying on. A big disadvantage of intramural research is that it is much easier to do relatively 'boring' but vitally useful research, e.g., spectroscopic tables, and systematic physical and chemical property measurements." Brooks, op. cit., footnote 39.

[47] Evidence of ferment has been most apparent at the Department of Energy. See Council on Competitiveness, "National Labs Meet With DOE," *Legislative and Policy Update*, vol. 3, No. 2, Jan. 28, 1991; Mark Crawford, "Domenici Bill to Broaden Labs' Missions," *The Energy Daily*, vol. 19, No. 14, Jan. 22, 1991, pp. 1-2; and "Roundtable: New Challenges for the National Labs," *Physics Today*, February 1991, pp. 24-35.

[48] This problem could be compounded by the recent Bush Administration proposal to charge users of Federal facilities, such as Brookhaven National Laboratory's synchrotron light source, a fee to cover operating costs. See Mark Crawford, "Researchers Protest User Fees at National Labs," *Science*, vol. 251, Mar. 1, 1991, p. 1016.

[49] In response to outside panel recommendations, three agencies with substantial inhouse research—the Department of Agriculture, the National Oceanic and Atmospheric Administration, and the Environmental Protection Agency—are seeking to expand their extramural programs, if Congress approves. See Elizabeth Pennisi, "New Policies at Three Federal Agencies Lend More Support to Outside Research," *The Scientist*, vol. 5, No. 2, Jan. 21, 1991, pp. 3, 5.

[50] See Bette Hileman, "Facts and Figures for Chemical R&D," *Chemical & Engineering News*, vol. 68, No. 34, Aug. 20, 1990, pp. 28-30.

Risk-Taking and Conservatism

Agency cultures promote differences in the kinds of projects selected for funding. In particular, agencies differ to a large extent in the amount of risk-taking in research that they encourage in scientific programs and by research managers. Risk-taking can be defined in a number of ways. Perhaps most important is that risky research is not considered in the mainstream, no specific outcome of the project is assured, and a large chance of failure exists (i.e., of not reaching the objectives set out in the proposal). However, the definition of risky research changes depending on the agency and field of inquiry, and to some extent, every research project is inherently "risky."

Within agency cultures some programs can assume more risks, because in the pursuit of a specific objective it is often wise to try some conservative, yet slower means, along with more experimental, less certain paths that might yield large payoffs. DOD claims to take the most risks in the course of its research program. DOD *expects* that most basic research will not attain the results that it originally proposed. Within the 6.1 category, DOD research managers assume that less than 30 percent of the projects will succeed; within 6.2, roughly 30 to 60 percent; and, within 6.3A, roughly 60 to 90 percent. Supporting unsuccessful projects is viewed as part of the business of finding projects that do pay off.[51]

In contrast, when there is no defined goal, how is risk defined—proposals that earn diverse ratings from peer reviewers? that are submitted by researchers with no track record? or that appear to be of marginal interest to the particular program weighing its merits? Attributes of risk are not clear cut. Further, the pace and impact of results emerging from federally funded research projects are no guide to their "riskiness," judged retrospectively.

Yet NSF and NIH managers claim that 90 percent or more of the projects that the agencies support are "successful." Success in the NSF and NIH context may mean that refereed publications were produced from the project. This satisfies the criterion of adding to the archive of knowledge, without measuring how that research was received by the community.[52] NSF has recognized a need to support more "high-risk" projects, instituting the Small Grants for Exploratory Research program to engender more risk-taking (see box 4-D).

Since it is obvious that not all scientific advances are made through slowly evolving research (epitomized by DOE's fusion energy program), but often with new and exciting projects, it is important for each Federal agency (and probably most research programs within it) to support both kinds of projects. This point is recognized by the scientific community when it simultaneously urges funds for new avenues of science as well as for the "science base," by which is meant the protection of evolutionary (and usually individual investigator, small team) research. While DOD addresses risk-taking through expectations for project outcomes and NSF has created a separate program, most agencies rely on program manager discretion to incorporate risk-taking. As priorities are set in new areas, it is very important to continue, and even augment, risk-taking in individual investigator research, and agencies should be encouraged to increase their efforts to fund risky projects.

Flexibility

When new priorities are introduced at a research agency, it must be flexible enough to reorient and develop relevant programs. Flexibility can be defined in a number of ways. But the most critical aspect of flexibility for funding scenarios in the Federal Government is the ability to make tradeoffs among scientific programs and to pursue growth by substitution—to start and stop programs, and to encourage new ideas without allowing fiscal constraints to hinder (or undermine altogether) their pursuit.

At the program level, flexibility is already provided in several ways. First, many agencies budget discretionary monies for managers to pursue new ideas. For example, some agencies (e.g., the Office of Naval Research) divide their pools of money into "core" and "accelerated" research initiatives. Core programs maintain expertise in certain areas and rely on principal investigators to propose goals for their research. Accelerated initiatives allow significant amounts of money to be quickly infused into a specific project area. Second, programs that disburse

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[51] These figures are a consensus among the Department of Defense managers whom OTA interviewed.

[52] For example, see Malcolm Gladwell, "Are Nobel Prizes for U.S. Vestiges of 'Golden Age'?" *The Washington Post*, Nov. 16, 1990, p. A6.

Box 4-D—Small Grants for Exploratory Research

Risk-taking is an important part of scientific research. In particular, the rate of scientific advancement witnessed this century could not have been achieved had the Nation not invested in some high-risk research along the way. However, the National Science Foundation (NSF) has been criticized that its funding decisions, based on a system of external peer review system, has become too conservative.[1] In response, NSF instituted in 1989 the Small Grants for Exploratory Research (SGER) program, which funds only small, high-risk research projects. In the words of a former NSF assistant director, who spearheaded the pilot program that led to SGER: "With the small amount of money, relatively, that NSF can give out, we cannot take care of all research needs. On the other hand, we have sufficient amounts of money to stimulate more creative and innovative research by playing a catalytic role."[2]

SGER grants are funded differently from ordinary NSF grants in several important ways. The definitive difference is that SGER grants go exclusively to researchers who are exploring "novel ideas" or "emerging research areas."[3] In addition, NSF eliminated formal, external peer review. Final recommendations on funding are left entirely up to the program manager, although the manager may certainly seek as much advice as he or she desires. More than in other NSF programs, grant applicants are encouraged to discuss their proposals with the project manager before submitting them in order to ascertain the proposal's chance for success. This reduces the number of unsuccessful proposals submitted, thus increasing the efficiency of the process and saving time. Also, this practice helps to foster a favorable working relationship between the researcher and the program manager. However, critics fear that this interaction might ". . . work against faculty who are not comfortable with selling themselves to others."[4]

Processing speed is another important aspect of the SGER program, as high-risk research often implies fast-paced. SGER grants are limited to $50,000, and the duration is no more than 2 years, usually only 1. Keeping grants on this smaller scale can make them easier to process.

In 1990, NSF funded 244 SGER proposals (while declining 210) at an average award of $34,254.[5] Also encouraging is the amount of activity in divisions, such as the biological sciences and Earth sciences, where the SGER program is being instituted for the first time.[6] The SGER program appears to provide an outlet for NSF to fund cutting-edge, high-risk research that the traditional NSF peer review system might not be equipped or inclined to support. The genre most served seems to be "cross-disciplinary" research, such as studies of natural disasters.[7] In addition, an Expedited Awards for Novel Research program (forerunner of SGER) survey of recipients found that 90 percent of SGER-funded researchers go on to apply for a regular NSF grant.[8]

SGER program spending is limited to 5 percent of each program. However, it appears to provide access to NSF funding for new researchers and, as one researcher put it, SGER support might result in ". . . fewer publications per dollar, but more chances for quantum leaps in advancing science."[9]

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[1] The National Science Foundation's own survey of 14,000 applicants who had been awarded or declined funding during fiscal year 1985 found that two out of three agreed with this statement: "NSF is not likely to fund high-risk exploratory research because the likelihood of obtaining favorable reviews is slim." See National Science Foundation, Program Evaluation Staff, *Proposal Review at NSF: Perceptions of Principal Investigators*, NSF 88-4 (Washington, DC: February 1988), p. 18.

[2] Nam Suh quoted in David Bjerklie, "Fast-Track Grants," *Technology Review*, vol. 93, No. 6, August/September 1990, p. 19.

[3] What follows, unless otherwise indicated, is based on National Science Foundation, Small Grants for Exploratory Research brochure, 1989.

[4] James M. McCullough, director, Program Evaluation Staff, National Science Foundation, "Responses to Bulletin Board Message About Quick-Response, Non-Reviewed Grants," Mar. 10, 1989, p. 5.

[5] Preliminary statistics on the Small Grants for Exploratory Research program provided by James McCullough, director, Program Evaluation Staff, National Science Foundation, personal communication, Jan. 23, 1990.

[6] National Science Foundation, unpublished data, Aug. 8, 1990.

[7] The fate of such proposals at the National Science Foundation, at least before the scope of the Engineering Directorate was enlarged, was problematic. See Alan L. Porter and Frederick A. Rossini, "Peer Review of Interdisciplinary Research Proposals," *Science, Technology, & Human Values*, vol. 10, No. 3, summer 1985, pp. 33-38.

[8] Investigators without prior National Science Foundation support are encouraged to apply to the Small Grants for Exploratory Research program, and the program indeed seems to attract many first-time applicants. See Bjerklie, op. cit., footnote 2, p. 19.

[9] Responses to McCullough, op. cit., footnote 4, p. 7.

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money by manager discretion have inherent flexibility. Specifically, program managers have the ability to continue or disband a research project, whereas in competitive peer reviewed grant programs many more persons—the ad hoc or standing peer review panel and the program manager—are asked to concur on a specific decision. Finally, in some programs, such as the Office of Space Science and Applications at NASA, managers are allowed some portion of their budget as discretionary. Discretionary money is important to foster new ideas within a "zero-sum" climate where money spent on one research project detracts from another.

Agencywide tradeoffs in budgeting and resource allocation are very important, but once a program has been initiated it is hard to end. This happens for a number of reasons. First, many people have become invested in working and supporting the program. Second, the program's political constituency may wish to see it pursued, and may lobby both Congress and the agency. Finally and most likely, given funding constraints, it may be very difficult to start a new program. It tends to be easier to redefine an old program to meet new goals, though it may not be immediately as effective as a completely new program.

OTA finds that agencies and managers throughout the Federal research system could be provided with the means, and perhaps incentives, to be more flexible. Ending one program and starting another could be made easier. More discretionary money could be provided, incentives for managers could be increased, and manager discretion accompanied by accountability and attention to success could be encouraged. Flexibility to adapt to research developments within a changing budget envelope is imperative. The production of excellence in research and the reduction of stress if funding does not keep pace with demand by the research community must go hand-in-hand.

Strategic Planning

Strategic plans have recently been employed by many of the research agencies as an important component of the research portfolio.[53] These agencies include the three services in DOD, CSRS in USDA, the NSF research programs (through NSB), and the Office of Space Science and Applications in NASA. While these agencies have always planned their near-term activities, many agencies have begun to codify the plans and publicly distribute them for comment.[54]

Strategic plans are very useful because they communicate within the organization, the Federal Government, and the research community the intentions of the research program over the next 5 to 20 years. They articulate the mission of the research investment and outline the steps necessary to attain intermediate and long-term goals. The mission may be as general as supporting research in a broad area, or as specific as solving a particular problem or developing the foundation for a specific technology. For instance, in the strategic plan for OSSA, NASA states that it will attempt to launch a combination of small and big satellite missions every year, thus showing a commitment to small science missions in space. If a program already has a clear idea of its mission and the means of attaining its goals, then the construction of a strategic plan is relatively easy. If that understanding does not exist, then the creation of a plan can be very useful in defining and pursuing those objectives.

Often the formation of a strategic plan is resisted within a program for fear of perpetuating relative funding differences and forcing decisions prematurely to pursue specific objectives. Judicious and regular revision of plans has led to a more realistic allocation of funds and allowed oversight by the executive branch and Congress to proceed smoothly. Rather than arbitrarily freezing the program, its potential can be highlighted and new options entertained within and without the current program structure.

While strategic plans are not the solution to all of the problems presented by the changing research economy, and can be used to justify decisions rather than to improve on them, OTA finds that strategic and contingency plans (especially when accompanied by ex post evaluation—see chapter 8) are elements that can be employed by the research agencies to plan for the future, increase communication, and accommodate new and continuing developments within the Federal system.

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[53] There is a school of thought (to which OTA substantially subscribes) that strategic plans are primarily useful for communication and have two negative potentials: 1) they may be put on the shelf and ignored, and 2) they may be implemented blindly. Strategic planning needs to be an institutionalized ongoing process, and plans need to be working documents that are constantly revised so the planning horizon rolls forward.

[54] Programs and agencies within the Department of Defense, the National Aeronautics and Space Administration, the National Science Foundation, and the U.S. Department of Agriculture have recently produced strategic plans. The National Institutes of Health is in the process of developing one.

Redirecting the Agencies and Addressing New Problems

What happens when the current mission of the agencies is no longer well formulated or appropriate? Many agencies have been chastised that their mission is either out of date or lost amid a multitude of programs. Observers further claim that the agencies are calcifying, pursuing programs and setting priorities because of tradition rather than national need.[55]

For example, DOE has been challenged that it does not support research that primarily seeks to solve the Nation's energy problems, but instead supports a broad array of research programs from high-energy colliders to radiation exposure in humans. Some claim that these problems would be better pursued in an agency like NSF and that DOE should concentrate on energy research. In a contrasting example, USDA has been repeatedly criticized for supporting a narrow research agenda. Biotechnology and other fields related to agriculture do not easily gain support within the USDA system. Critics point out that the USDA system does not coordinate well and many research opportunities fall through the cracks between ARS, CSRS, the Forest Service, and other programs.[56] In a third example, after a series of large programs had not lived up to expectations (e.g., the Space Shuttle and the Hubble Space Telescope), a Presidential commission was created to conduct a comprehensive review of NASA priorities and procedures.[57]

Many agency problems result from Federal attempts to cope with tighter budgets and setting of priorities. OTA finds that the Federal agencies are responsive to changing national needs, but are limited by the program structure and budget. Agency missions were defined many decades ago, often when budgets were expanding, and these mission statements were ambitious. Agencies always seek growth as an overall objective. But decisionmaking structures do not serve as well when tradeoffs between agency programs must be made and managers have little incentive to terminate programs.[58] For the research system to thrive in the 1990s, the termination of some programs in favor of others may be required.

Some also question whether the scope of many agencies' programs should be reduced so that whatever they decide to do they can do well. Perhaps lessons learned at DARPA are instructive. DARPA rarely pursues a problem without the required funds, and attempts not to start programs at low levels (which implies that the budget must free up to accommodate the program sometime in the future). DARPA personnel regard this philosophy as crucial to their success.

In summary, crafting goals and missions for the Federal agencies as the research economy changes is not just a matter of the scientific objectives, but also of management. The agencies were created at different times over the last half century and carry with them cultural traditions and organizational structures. As new goals are assigned to the research system, Congress and the executive branch must pay special attention to the capabilities and decisionmaking mechanisms of each agency. This includes the methods by which priorities are implemented in the selection of researchers and projects for support. OTA considers these methods next.

Funding Allocation in the Federal Agencies

When applying for Federal research funds, researchers submit a proposal. In general, a proposal requests support for an individual, a specific project, or a center,[59] and is submitted to a particular program in an agency for review. The process of review can be thought of as a continuum of methods ranging from soliciting advice from experts outside the agency, or *peer review*, to relying solely on the judgment of the research officer who must defend decisions to award or decline funding; this might be called *manager discretion*. In practice, a mix of these methods, even within the same agency, is common.

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[55] Remarks at ''OTA Workshop on Costs of Research and Federal Decisionmaking,'' July 9, 1990.

[56] Office of Technology Assessment, op. cit., footnote 34; U.S. Congress, Office of Technology Assessment, *U.S. Investment in Biotechnology*, OTA-BA-360 (Washington, DC: U.S. Government Printing Office, 1988); and U.S. General Accounting Office, *Biotechnology: Analysis of Federally Funded Research* (Washington, DC: U.S. Government Printing Office, 1986).

[57] Advisory Committee on the Future of the U.S. Space Program, op. cit., footnote 18.

[58] Indeed they are encouraged to keep programs in operation. See Harvey Averch, ''Policy Uses of 'Evaluation of Research' Literature,'' OTA contractor report, July 1990. Available through the National Technical Information Service, see app. F.

[59] For a case study analysis of Federal mechanisms used to fund university research, see U.S. General Accounting Office, *University Funding: Assessing Federal Funding Mechanisms for University Research*, GAO/RCED-86-75 (Washington, DC: February 1986).

Peer Review

''Peer review'' describes a family of methods used to make funding decisions about research projects. It usually comprises a multistaged process, where reviews of the proposal are solicited from experts in the scientific subdiscipline of the proposal. Reviewers are most often asked about the technical excellence of the proposal, the competence of the researchers, and the potential impact of the proposed project results on a scientific discipline or interdisciplinary research area. Peers may also be asked about the project's relevance to the objectives of the funding program. The proposals and reviews may then be considered by a panel of experts, and competing proposals compared. The panel eventually ranks the proposals in the order in which they think the proposed projects should be funded.

There are distinct advantages to this form of proposal review: the participants are acknowledged experts who make absolute and relative judgments of proposal quality, or ''scientific merit,'' and who offer their time on a largely volunteer basis. The process is expected to operate according to values of fairness and expediency. However, at the two agencies that depend most on external peers, NSF and NIH, problems with and suspicions about systematic biases in proposal review have produced a series of studies and self-studies.[60] Such studies raised questions about the composition of review panels and the fate of proposals submitted by investigators at research universities.[61]

Probably the most predominant criticism of peer review, and the one that has troubled Congress the most, has been the allegation that it is controlled by an ''old boys network,'' which informally favors those like themselves, and that decisions are made behind closed doors where aspersions can be cast against a researcher without providing a forum for refuting them. Attempts have been made at both NSF and NIH to correct faults found in peer review, but neither agency would suggest that all of the problems have been fixed. Rather, given the strength of peer review in soliciting expert opinion, they ask ''what method is *better*?''[62]

Manager Discretion

Manager discretion as a project selection method refers to agency investment in the expert judgment of a single decisionmaker or administrator—the program manager.[63] This is not only the *technical* judgment of the manager, but also his or her ability to put together the best portfolio of research to achieve the goals of the program. Manager success is therefore seldom evaluated on the basis of one project or before a series of projects are complete. Rather, it is based on the success of an entire research program. In agencies that rely heavily on manager discretion, there is strict accountability of managers for program decisions. But managers do not work in isolation; there is oversight from superiors, and inhouse advice is readily available. In particular, technical judgments of inhouse staff are commonly solicited, and additional reviewers can be tapped from outside the agency.

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[60] These are reviewed in D.E. Chubin and E.J. Hackett, *Peerless Science: Peer Review and U.S. Science Policy* (Albany, NY: SUNY Press, 1990), chs. 2 and 3; U.S. General Accounting Office, *University Funding: Information on the Role of Peer Review at NSF and NIH*, GAO/RCED-87-87FS (Washington, DC: March 1987); and NIH Peer Review Committee, ''Sustaining the Quality of Peer Review: A Report of the Ad Hoc Panel,'' unpublished report, December 1989. Early studies of note include: NIH Grants Peer Review Study Team, *Grants Peer Review: Report to the Director, NIH Phase I* (Washington, DC: December 1976); Grace M. Carter, *What We Know and Do Not Know About the Peer Review System*, report N-1878-RC/NIH (Santa Monica, CA: RAND Corp., June 1982); Stephen Cole et al., *Peer Review in the National Science Foundation: Phase I of a Study* (Washington, DC: National Academy of Sciences, 1978); and Jonathan R. Cole and Stephen Cole, *Peer Review in the National Science Foundation: Phase II of a Study* (Washington, DC: National Academy of Sciences, 1981).

[61] For a recent example of such analysis at the National Science Foundation, see James McCullough, ''First Comprehensive Survey of NSF Applicants Focuses on Their Concerns About Proposal Review,'' *Science, Technology, & Human Values*, vol. 14, No. 1, winter 1989, pp. 78-88, and associated commentaries that follow the article.

[62] See Jon Turney, ''End of the Peer Show,'' *New Scientist*, vol. 127, Sept. 22, 1990; and Jeremy Cherfas, ''Peer Review: Software for Hard Choices,'' *Science*, vol. 250, Oct. 19, 1990, pp. 367-368.

[63] What OTA is calling ''manager discretion'' is discussed in the organizations literature as a management tool or approach that springs, for example in the case of the National Aeronautics and Space Administration space program, from ''. . . the complex conceptual, planning, administrative, and evaluative tasks facing the agency and its contractors.'' See Karl G. Harr, Jr. and Virginia C. Lopez, ''The National Aeronautics and Space Administration: Its Social Genesis, Development and Impact,'' *Managing Innovation: The Social Dimensions of Creativity, Innovation and Technology*, S.B. Lundstedt and E.W. Colglazier (eds.) (New York, NY: Pergamon Press, 1982), p. 181.

Manager discretion has many advantages as a funding allocation mechanism. First, because program managers are intricately involved in the development of a program, they can best gauge the relevance of projects selected for funding to program objectives. Second, manager discretion allows an agency to implement new goals quickly, since it is easier to instruct managers to alter selection criteria or allocation methods (and hold them accountable for doing so) than to convince external peer reviewers to weigh factors others than technical merit in the rating of proposals. Finally, the ethos of manager discretion can result in the funding of proposals that do not reflect the collective wisdom in vogue. As put by one manager at the Office of Naval Research, where manager discretion is the rule: "We don't take votes in the science community."[64]

However, manager discretion can also suffer from isolation—soliciting too little opinion from outside of the agency, as well as relying foremost, and sometime solely, on the technical judgment of the program manager. Manager decisions can also be seen as capricious, since they are not based on a consensus among peers. Also, wherever manager discretion is used as a decisionmaking device, it assumes an organizational structure that recognizes managerial responsibility for activities and objectives within time and cost limits.

Although on the surface peer review and manager discretion seem very different, many agencies use a combination of the two in their decisionmaking. What follows is a brief description of the funding allocation methods in the major research agencies. For a more detailed discussion, see appendix C.

Agency Overview

NIH can be considered the original site of peer review in the Federal Government, beginning with the National Advisory Cancer Council in 1937.[65] Today, NIH has an elaborate "study section" system for soliciting and reviewing proposals from extramural researchers. Section "secretaries" are pivotal in proposal processing. Study section recommendations are directed to 1 of 13 institutes and must ultimately be approved as funded projects by the appropriate advisory council. NIH intramural researchers located in NIH laboratories around the country compete for separate support. NIH uses almost 100 chartered panels to recommend decisions about the relative merits of proposals.[66]

DOD research agencies rely primarily on inhouse review and manager discretion. DARPA in particular is known for its strong program managers. DARPA solicits proposals tailored to a field of interest and specific research objectives. Funding is awarded (and withdrawn) almost exclusively at the discretion of the project manager. The Office of Naval Research controls most of the 6.1 funding for the Navy and is also noted for the independence of its program managers who are often referred to as "czars." The Air Force Office of Scientific Research disburses all of the Air Force's 6.1 budget, both to its own laboratories and to universities, with inhouse review and manager discretion decisive in project selection. Army research programs are decentralized, and inhouse review is used to allocate monies to universities and numerous DOD laboratories. The University Research Initiative in the Office of the Secretary of Defense supports additional research at universities. The funding, however, is allocated through the services and DARPA.

Research proposals at NASA are processed differently by the Office of Space Science and Applications and by the Office of Aeronautics, Exploration, and Technology. At OSSA, proposals relating to future flight missions are solicited through Announcements of Opportunity (AOs). Research Announcements are more modest in scope than AOs, and can solicit "guest" observers (who will participate in a mission after the original investigators) and support theoretical work. Unsolicited proposals are also considered. Funding is based primarily on technical merit reviewed by an expert panel selected by the program manager, an inhouse group, or an outside contractor. NASA staff provide further review to determine feasibility and mission relevance. Proposals are ranked and the program manager selects from the top 20 to 40 percent. Division managers must approve these selections.[67] At OAET, proposals are solicited through Requests for Proposals. All responses are reviewed inhouse, and most grants and contracts are administered by NASA laboratories. In all, one-half of OAET's total R&D funds is disbursed to the laboratories (chiefly Ames, Langley, and Lewis), while 30 percent goes to industry, and 20 percent to universities.

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[64] OTA interviews at the Office of Naval Research, spring 1990.

[65] The National Institutes of Health epitomizes how much project selection can be influenced, in the long run, by the very scientists who receive the funds. See Nicholas C. Mullins, "The Structure of an Elite: The Advising Structure of the U.S. Public Health Service," *Science Studies*, vol. 2, 1972, pp. 3-29.

[66] The National Institutes of Health is the largest part of the Department of Health and Human Services; only one other component of this department, the Alcohol, Drug Abuse, and Mental Health Administration, supports extramural research.

DOE's civilian science programs use many of the same proposal review techniques as NASA, with peer review of scientific merit and final judgment by the program manager. All proposals are solicited through Broad Agency Announcements. The majority of research funds are awarded to the laboratories, and these expenditures are estimated in the budget request for DOE. Almost all of the agency's defense research is done at the laboratories; funding is competed among them and distributed on the basis of inhouse reviews.

NSF funds only extramural research.[68] It uses program announcements and, through its system of "rotating" program managers, routinely circulates members of the research community into the agency's decisionmaking apparatus. Although peer review is the guiding principle of NSF proposal review, its form varies greatly within and across agency directorates, divisions, and programs.

USDA is a multilimbed agency. The funding procedures of the Agricultural Research Service are highly centralized and totally inhouse. Proposals are received in response to an annually revised 5-year National Program. They are sent for external review only *after* the decision to fund has been made and only to approve the dollar amount of support. The Agriculture Grants Program of the Cooperative State Research Service is a separate arm of USDA. Outside panels rank proposals and, along with program managers, determine funding levels. CSRS also has "nationally targeted programs" and "special programs," the latter being congressionally earmarked funds. Both categories are supervised inhouse. The Forest Service is another arm of USDA, with stations scattered around the United States competing for funds from the National Program. Research work unit descriptions are solicited from all of the laboratories and are competed at the national level; outside review is rarely solicited.

Blurring of Peer Review and Manager Discretion

This overview illustrates the various combinations of peer advice and manager discretion used in the research agencies. Some research agencies have always used a particular method—DOD has consistently relied on manager discretion augmented by informal reviews. Some agencies have recently altered their methods.

For instance, NSF renamed its proposal review process "merit review" in 1986 to reiterate that "merit" consists of more than peer judgments, especially relevance to agency missions.[69] Likewise, NIH stresses the role of institute advisory councils in weighing priority scores against program relevance[70] (for an example, see box 4-E). While it has always been the case that technical merit is a necessary but not sufficient condition for research funding at agencies other than NSF and NIH, the exercise of manager discretion in the selection processes of these peer review-based agencies has become more explicit.

The issue is not which method, peer review or manager discretion, is better, but that either one, or a combination, can be used effectively to address

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[67] Other discretionary money (representing about 10 percent of the budget) is available to the division director and the program manager. It is disbursed for projects of higher risk, or for specific needs not addressed through the procedures described above, using a less formal procedure (sometimes only with internal review).

[68] For example, in fiscal year 1989, the National Science Foundation (NSF) received 44,300 proposals and made 16,700 awards. The agency supports the research of 18,900 scientists (including salary for an average of 2 months each year), 3,600 postdoctoral researchers, and 15,600 graduate students. The average award amount to individual investigators ranges across directorates from $50,000 to $150,000. Comparable information in all of these categories, over the last decade, is lacking for the other agencies except the National Institutes of Health and the Department of Veterans Affairs. See U.S. Congress, Office of Technology Assessment, "Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System," staff paper of the Science, Education, and Transportation Program, April 1990, pp. 4-7, and table 1. Since publication of the OTA staff paper, NSF has developed revised numbers for *competitively reviewed* proposals: 27,300 received and 8,400 awarded with a median annual award of $55,000. Linda Parker, National Science Foundation, personal communication, Jan. 23, 1990.

[69] National Science Foundation, Advisory Committee on Merit Review, *Final Report*, NSF 86-93 (Washington, DC: 1986).

[70] For a historical perspective, see Stephen P. Strickland, *The Story of the NIH Grants Programs* (Lanham, MD: University Press of America, 1989).

Box 4-E—Fine-Tuning Project Selection at NIGMS

The mission of the National Institute of General Medical Sciences (NIGMS), one of the 13 National Institutes of Health, is the support of basic research in the life sciences. Early in 1990, the National Advisory General Medical Sciences (NAGMS) Council issued new guidelines that expand the factors taken into consideration by the scientific staff in making project funding decisions.[1] "In times of extremely constrained funding," the NAGMS Council stated that "... the Institute [must] promote the broadest possible diversity of ideas and approaches, ..." and "... encourage the ideas and talents of established investigators and of the young or new investigators who will provide the next generation of research accomplishments." The NAGMS Council recommended a policy authorizing that special consideration be given to a highly rated application from an investigator "... who has no other significant source of research support ..." as opposed to such applications from investigators "... whose total research support from all sources, including the pending award, exceeds $500,000 (direct costs)."

Under this policy, the advisory council chose to free up funds by: 1) reducing the amount of funding received by some investigators in the $500,000 plus category, 2) not approving two awards for projects that were within the "theoretical" NIGMS payline, and 3) cutting 30 percent of the competing continuation grants (60 out of 200) beyond the 12 percent across-the-board reduction. As a result of this shift of funds, 6 percent of institute awards (n=21) were made to "... grantees who had no other significant source of research support and who also had percentiles that were beyond the theoretical Institute payline, ... " i.e., who would not have been funded under the traditional NAGMS guidelines.

What are the lessons derived from this advisory council action? There are at least two appraisals. The positive one is that an NIH advisory council is searching for ways to support investigators without compromising the integrity of either the peer review system or the research to be funded. Priority scores were intended as the chief input to, but not the sole determinant of, award decisions. The NAGMS Council recognizes the imprecision of priority scores at the margin, and does not embrace their use as the sole criterion for funding.

An appraisal that is more negative is most clearly stated in a letter sent in June 1990 to Acting NIH Director William F. Raub.[2] Citing "... little comfort in the idea that the change is only temporary, ..." the author notes that "... there will always be a case to be made for redistributionist policies, because there are always more losers than winners and many of the losers are quite meritorious." He protests that peer judgments about the quality of science will be secondary to consideration of the financial condition of the applicants.

Another criticism is that the new NAGMS policy is merely another in a series of ad hoc responses to the problem caused by the insufficient number of new and competing grants, "... rather than looking broadly at NIH's total research and training portfolio and the adequacy of its budget to support it. ... NIH has other programs to achieve other purposes: for example, the special program for young investigators. We support those programs and want them to be adequately funded. But the core NIH research grant programs should not be used to solve problems extraneous to their proper goals."[3]

Expanding the pool of supported investigators, especially the "next generation," and diversifying the approaches to research that fall within the NIGMS mandate is part of the NIH mission. On the other hand, the NAGMS policy is seen by some as tampering with the traditional NIH review system. This use of discretionary action by program officers and advisors should be applauded, but continues to be a source of debate in government and the scientific community.

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[1] The following is paraphrased or quoted from National Advisory General Medical Sciences Council, "January 1990 Motion and Guidelines Regarding Funding Decisions," unpublished manuscript, Feb. 8, 1990.

[2] Excerpts from the letter are used below to illustrate generic points probably held by others. The anonymity of the author is preserved.

[3] Ibid.

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programmatic goals (and the choice of which method depends on the goal).[71] In general, OTA has found that the agencies will often adapt funding allocation strategies to new goals.

Set-Asides and Formula Funding

In addition to the mainstream disbursal of funds, agencies often allocate funds using other types of programs. The two prominent categories of such programs are *set-asides* and *formula funding*. While their origins differ, each method of funding clearly allows the Federal research agencies the discretion to pursue certain national needs by applying a different or reordered set of criteria to the selection of research performers.

Set-aside programs are agencywide discretionary actions. They select one characteristic that captures a need not served by mainstream proposal review and restricts competition for research funding to a pool of eligibles who qualify by virtue of that characteristic. Thus, there are set-asides for women, ethnic minorities, young investigators, investigators located at traditionally nonresearch institutions, and investigators residing in States that have been underrepresented in the amount of Federal research funds they receive relative to their share of the general population or the number of undergraduates they enroll. (There are set-asides in other agencies as well. See box 4-F.)

The assumption underlying set-aside programs is that there are capable researchers everywhere who—for lack of opportunity or obvious disparities in experience—are disadvantaged in the ordinary competitive proposal process. The solution is a separate competition, still organized around the criterion of technical merit, that pits like against like. (For a model of an NSF set-aside that attempts simultaneously to strengthen institutional research capability and geographic diversity, see box 4-G.) For some researchers, set-asides are the only way into the Federal grants system; for others it is a springboard to continued competition in regular agency programs.

Photo credit: U.S. Department of Energy

Scientists study the results of a nuclear magnetic resonance experiment. Several agency set-aside programs address the recruitment and retention of women in scientific fields.

Formula funding can be traced to the Hatch Act (1887), which authorized the allocation of Federal funds to land-grant universities for the conduct of research.[72] These funds are a kind of categorical or block grant disbursed to the States, which enjoy considerable discretion in their use. Typically, the subject areas to be addressed by formula-supported research are selected by directors, deans, department heads, and faculty in the land-grant institutions, within the broad guidelines of the enabling legislative acts. Peer review methods may be employed at this decentralized level.[73] In agriculture, competitive grant funding is used to augment formula funding that expands the science base, e.g., new research in agricultural biotechnology.

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[71] "It is much harder to rely on managerial discretion in an agency that has responsibility for the health and progress of science. There is also probably value in a variety of blends between managerial discretion and peer review in different agencies and in different programs of a single agency." Brooks, op. cit., footnote 39.

[72] The roots of formula funding are perhaps the strongest in agriculture, where Hatch and the Smith-Lever Act (1914) formulas (the latter directed to agricultural extension services) prescribed allocations to each State proportional to the magnitude of its agricultural enterprise. These proportions are indexed roughly to annual cash sales of agricultural products in the States and the investment of State funds in the State Agricultural Experiment Stations. For details, see Don Holt, Illinois Agricultural Experiment Station, "Recapturing the Vision: The Case for Formula Funds," proceedings of the 1989 Annual Meetings of the Agricultural Research Institute, Bethesda, MD, May 1990.

[73] For example, the criteria for project selection in agriculture include: potential economic and social importance of the research activity to the State, region, and Nation; potential for the activity to generate other research support; need to fill gaps in agricultural knowledge; and need to provide continuity in long-term research programs. See Don Holt, Illinois Agricultural Experiment Station, "Mechanisms for Federal Funding of Agricultural Research and Development," mimeo, August 1988, p. 4.

Box 4-F—Small Business Innovation Research Program (SBIR)

The Small Business Development Act of 1986 (Public Law 99-443) requires Federal agencies that spend more than $100 million annually on extramural research or research and development (R&D) to set aside 1.25 percent (when fully operational) of those funds for a Small Business Innovation Research (SBIR) program.[1] These programs are intended to encourage innovation by allocating grants or contracts specifically to small businesses conducting research on relevant topics. Minority firms are also encouraged to compete.

The notion of a set-aside program for small businesses, initiated by the National Science Foundation in 1977, was initially disparaged by the academic research community, who viewed the program as a drain on available funds. It was instituted governmentwide in 1982, and now provides substantial funds for science and technology-intensive firms conducting research on agency objectives considered too risky to interest financial investors. The seed money supplied by the Federal Government for the initial phases of research is leveraged in later phases by private capital. The receipt of SBIR funds is considered an asset by some investors, who feel that it reflects a measure of endorsement by Federal granting agencies.

The program has three phases. In phase I, projects are tested for scientific merit and feasibility. In phase II, the principal research effort, successful phase-I projects are supported for up to 2 years. Products or services that reach phase III are developed for private or government use. Before a project can enter phase III, it must secure additional sources of support because SBIR funding ceases after phase II.

In fiscal year 1990, the U.S. Department of Agriculture funded 32 phase-I and 13 phase-II projects at a total of $14.1 million. The award rate was 10 percent. In the same year, the U.S. Environmental Protection Agency funded over 15 phase-I and nearly 20 phase-II projects at no more than $25,000 each. The Department of Commerce spent $1 million on 9 phase-I and 2 phase-II grants in fiscal year 1990. One of the largest contributors, by virtue of the size of its budget, is the National Institutes of Health, which spent $73 million on SBIR in fiscal year 1990. Biotechnology companies have fared well under the NIH SBIR program and praise the program for giving them the boost needed to conduct high-risk research.[2]

SBIR was reauthorized in 1987 for an additional 5 years—until 1993. It continues to be one of the few sources of direct Federal support for applied R&D conducted by small companies.

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[1] This act is based on a 1982 act (Public Law 97-219) and a successful experimental program of the National Science Foundation (NSF). The sources for what appears below are program solicitations of the Small Business Administration's and NSF's Small Business Innovation Research Programs, *Washington FAX*, Sept. 24, 1990, and National Science Foundation staff, personal communications, December 1990.

[2] But see Jeffrey Mervis, "Scientific Conflict of Interest Regulations Offer Loophole to Small Business Program," *The Scientist*, vol. 5, No. 6, Mar. 18, 1991, pp. 1, 8-9.

Advocates of formula funding state that:

> Formula funds created the public institutional structure of U.S. agriculture and remain essential to preserving the unique strengths of key institutions. Formula funds leverage much State and private support for agricultural research. They distribute costs in proportion to producer, consumer, and spillover benefits. Formula funds provide much needed continuity to programs that are otherwise fragmented by the short-term, unpredictable nature of gifts, grants, and contracts. They are needed to offset unrecoverable indirect costs of projects, including . . . depreciation on buildings and equipment. . . . By decentralizing scientific priority setting and operational management, they avoid capricious top-down decisions and overcome the deleterious averaging effect of consensus-based management. Critics of formula funds focus on the need for peer review, incorrectly implying that formula funds are not allocated competitively. The peer review issue clouds other important issues, including . . . the inability of typical peer review panels to apply site- and situation-specific criteria.[74]

Yet many still question the review received for formula funded projects, and favor funds awarded through openly competitive programs as "better spent."

Both set-asides and formula funding represent a form of legislated and/or within-agency recognition that certain research goals cannot be achieved via conventional proposal review. Thus, agency programs are created to direct funding that satisfies

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[74] Holt, op. cit., footnote 72, p. 1.

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Box 4-G—The NSF EPSCoR Program: Geography and Research Capability

Nowhere has the concern for regional distribution of Federal research funds been better institutionalized than in the National Science Foundation's (NSF) Experimental Program to Stimulate Competitive Research (EPSCoR).[1] Established in 1978, EPSCoR awards ". . . small amounts of money to 16 have-not States and Puerto Rico to use as a magnet to help their universities and local industries excel in one or more areas of science and engineering."[2] The States are Alabama, Arkansas, Idaho, Kentucky, Louisiana, Maine, Mississippi, Montana, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, Wyoming, and the Commonwealth of Puerto Rico.

The EPSCoR States have formed a nonprofit organization, the Coalition of EPSCoR States, that argues for greater Federal investment in the development of science and engineering capability nationwide. Relative to the Nation as a whole, the Coalition points out, EPSCoR States ". . . have low per-capita incomes, high unemployment, poor schools, retarded economic development, and low levels of science education attainment and scientific manpower production."[3] The EPSCoR States received 5.4 percent of Federal R&D funds in 1980, and 5.6 percent in 1987. By improving the competitive position of States with underdeveloped science and engineering fundamental research infrastructures, EPSCoR hopes to contribute to the health of all research and development (R&D) within the United States.[4]

EPSCoR as Antidote

Selection as an EPSCoR-eligible State allows the State to compete for a research enhancement award of between $3 and $5 million over 3 to 5 years. The money is awarded to a lead institution within a State to implement the proposed State R&D plan, to stimulate academic research activity, and to enhance the competitive stature of institutions in select research areas.[5] The size of a State's EPSCoR award is determined by the quality, number, and type of projects; the current status of its research environment; the scope and magnitude of the proposed improvements; and the potential to demonstrate significant change as judged by merit review.[6]

The objectives of EPSCoR are to increase the competitiveness of participant scientists and engineers—working as individual investigators, in research groups, or in a research center—to obtain other R&D funds; to effect permanent improvements in the quality of science and engineering research and education programs; and to ensure that improvements achieved through EPSCoR-initiated activities continue beyond the end of the EPSCoR grant period.[7]

EPSCoR can also leverage investment from other sources; and, for every Federal dollar, three local dollars are being invested in support of EPSCoR from industry and other sectors.[8] In Montana, for example, about 220 researchers have received aid and about one-half of them have gone on to win Federal grants through NSF's regular merit review system. Another 20 percent have won support from non-Federal sources. South Carolina has enjoyed similar success: the mathematics departments at both Clemson University and the University of South Carolina ranked 47th and 62d, respectively, in outside support after participating in EPSCoR. Previously, neither had been among the top 100.[9]

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[1] National Science Foundation, Division of Research Initiation and Improvement, "Experimental Program To Stimulate Competitive Research, Program Plan FY 1989-1995," unpublished report, n.d.

[2] Jeffrey Mervis, "When There's Not Enough Money To Go Around," *The Scientist*, vol. 4, No. 8, Apr. 16, 1990, pp. 1, 8.

[3] Coalition of EPSCoR States, "EPSCoR: A State-Based Approach to Expanding American Research Capacity," a congressional briefing paper, Feb. 20, 1990.

[4] Joseph G. Danek, "A Model Program for Expanding the Nation's Science and Engineering Infrastructure," summary for the annual meeting of the American Association for the Advancement of Science, New Orleans, LA, Feb. 20, 1990.

[5] Joseph G. Danek, National Science Foundation, personal communication, December 1990. By its descriptive language, the National Science Foundation apparently does not like to emphasize that EPSCoR is an "equity" program; rather it refers to EPSCoR as a capacity building program.

[6] National Science Foundation, op. cit., footnote 1, p. 2.

[7] Ibid., p. 1.

[8] Danek, op. cit., footnote 4.

[9] Colleen Cordes, "Tiny NSF Program Hailed as Model for Broader Distribution of U.S. Funds," *The Chronicle of Higher Education*, vol. 36, No. 45, July 25, 1990, p. A17.

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Box 4-G—The NSF EPSCoR Program: Geography and Research Capability—Continued

Prospects for Emulation

Several statewide EPSCoR initiatives have created ongoing organizations dedicated to the long-term support of science and engineering research. Included are the following: Montanans on a New Track for Science; Louisiana Stimulus for Excellence in Research; Oklahoma Center for the Advancement of Science and Technology; and Arkansas Science and Technology Authority.[10] Through participation in the EPSCoR program, these and other States have been able to target their weaknesses and make significant strides in meeting the needs and improving the quality of their research communities in select areas.[11]

EPSCoR was funded at roughly $11 million in fiscal year 1991. The EPSCoR Coalition is seeking additional funds from NSF and for the establishment of similar programs in other agencies. The National Aeronautics and Space Administration (NASA), for example, is embarking on a program to help academic researchers compete for NASA funds and to improve overall scientific literacy in underfunded States. The U.S. Department of Agriculture is considering the provision of seed grants to scientists who have not received competitive grants from them in 5 or more years.[12]

The prospect of redistribution worries critics of EPSCoR who fear a dilution of research capability. They claim that EPSCoR undercuts peer review. But because the program aims to make States more competitive at a national level, it pits them against one another for limited funds.[13] Acting Director of the National Institutes of Health, William Raub, also suggests that an EPSCoR-type program may not be transferable to the health care arena. Many poorly funded colleges simply do not possess an adequate research infrastructure; there is no clinical program or animal facility in which such research might be supported.[14]

Thus, if expanding the EPSCoR model across Federal agencies is to be seen as a serious intervention, then several questions remain. In the face of a tight Federal budget, how much money should be devoted to assisting scientists and engineers in some States to become more competitive? (Would doubling or tripling the amount of the annual EPSCoR award multiply or hasten returns?) At what level has a State made enough progress to graduate from EPSCoR, or fallen behind enough to be added to the list?[15]

Quantitative measures of success must also be developed. Areas that might be examined include: the extent of increased competitiveness for Federal R&D funding among individual investigators and research groups, the scope and effectiveness of departmental and institutional enhancements of the research environment, and the demonstration of long-term State financial support of EPSCoR to advance the cause of education and human resources for science and engineering.[16] If broader geographic distribution of Federal research funding is sought, the EPSCoR model could be emulated.

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[10] Danek, op. cit., footnote 4.

[11] National Science Foundation, op. cit., footnote 1, p. 2.

[12] Mervis, op. cit., footnote 2, p. 12. The Department of Energy, the Department of Defense, and the Environmental Protection Agency were all directed by the 101st Congress to introduce EPSCoR programs. See Audrey T. Leath, ''Congress Heaps Funds on EPSCoR for Research in 'Have-Not' States,'' *Physics Today*, February 1991, pp. 77-78.

[13] Cordes, op. cit., footnote 9, p. A17.

[14] Ibid., p. 12.

[15] Ibid., p. A17.

[16] Given the concentration of ethnic minorities in many EPSCoR States, the human resources potential of the program to increase participation in scientific careers has yet to be emphasized, except in Puerto Rico. Established in 1980 with EPSCoR and University of Puerto Rico support (and subsequently from the National Science Foundation's Research Centers of Excellence Program in 1988), the Resource Center for Science and Engineering offers programs at every stage of the educational pipeline. The university has awarded 91 Ph.D.s in the sciences in the last decade, making it the leading grantor of doctoral degrees to minority scientists. See Manuel Gomez, ''A Comprehensive Regional Center to Develop Human Resources in Science and Mathematics in Puerto Rico,'' presented at the Fifth EPSCoR Conference, Aug. 15, 1990.

longstanding or emerging needs in novel ways. Such departures are almost always seen as diluting quality, i.e., trading off excellence in research for the fulfillment of ''subsidiary'' agency objectives. But at what point do these objectives become central to the agency mission, or address multiple deficiencies in the distribution of research funds and the execution of research?

This question cuts to the core of this study: What does the Federal Government expect research fund-

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ing to accomplish? Entering the 1990s, OTA foresees agency funding criteria and methods, on the one hand, and researcher expectations, on the other, changing to accommodate a wider range of demands imposed on the Federal research system.

Summary

In this chapter, OTA has introduced the Federal research agencies, and outlined their priority setting and funding allocation mechanisms. In general, the Federal agencies are characterized by diversity, pluralism, decentralization, and a division of labor, but together they form a comprehensive research system.

Each agency follows its research mission, but there is much disagreement, both within the agencies and in various research communities, over what constitutes that mission. Agency programs and research foci change in response to shifting priorities, but as with all large organizations, this change occurs slowly. The pace of change is especially hampered in research by the long-term nature of the work and by the inability to reorient programs quickly. Risk-taking, flexibility, strategic planning, and redirecting agencies are longstanding challenges.

Agencies use a combination of peer review and manager discretion to allocate funds. In addition to the mainstream programs, agencies also create set-aside programs to foster the development of underprivileged parts of the research community. In another type of funding, some agencies (especially USDA) disburse funds by formula, which are allocated as block grants to specific institutions.

Agencies have a good sense of their research constituencies and attempt to cultivate both their development and long-term responsiveness. Nevertheless, much of the brunt of the pressure on the scientific community is reflected in agency programs. Program managers must make tough decisions about where to allocate funds and how to support personnel, facilities, and equipment.

In summary, agencies have the resources to adapt to changing internal and external priorities. However, Congress may wish to increase agencies' ability to set and coordinate goals and to address other issues. These issues—priority setting at several levels of decisionmaking, costs of research, human resources for the research work force, and data collection and analysis on the Federal research system—are discussed in the following chapters.

CHAPTER 5

Priority Setting in Science

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CHAPTER 5
Priority Setting in Science

> *Even if we could double the science budget tomorrow, we would not escape the need to establish priorities. . . . At present we have no well-defined process . . . for systematically evaluating the balance of the overall Federal investment in research and development and in the variety of fields that we try to serve.*
>
> Doug Walgren[1]

Introduction

At every level of decisionmaking in the Federal research system, goals are outlined and translated into plans for their achievement. For the system to provide both continuity and flexibility in research funding, priorities are set, chiefly through the budget process. Both the executive and legislative branches have mechanisms to set priorities, many of which were detailed in the two previous chapters. However, broad priority setting is generally resisted by the recipients of Federal funding because it orders the importance of research investments, often in ways that groups within the scientific community do not support. This problem is especially perplexing, because there are few mechanisms and no tradition of ranking research topics across fields and subfields of inquiry.

Priority setting can help to allocate Federal resources both when they are plentiful, as they were in the 1960s, and when they are scarce, as is expected in the early 1990s. Governance requires that choices be made ultimately to increase the benefits and decrease the risks to the Nation. For example, decisionmakers in the Office of Management and Budget (OMB) routinely compare the projected costs, benefits, and risks of certain programs. The benefits of research increase technological capability, national security, health, economic activity, and educational resources. Setting priorities is a way the government achieves national goals.

In the grand scheme of things, research is one Federal concern among many, routinely costing less than 2 percent of the domestic and defense budgets. Research has traditionally been a favored part of the budget—only four budget areas have consistently received increases over the 1970s and 1980s: entitlements, defense, payments on the debt, and research.[2] Consider the President's proposed fiscal year 1991 budget. The items in this $1.4 trillion budget are organized under five themes. The first theme, "Investing in the Future," features science and technology items most prominently among the 10 categories listed (see table 5-1). Five of these categories explicitly mention science or research goals.

What the Federal Government values more or less in research can be inferred in part from the Federal budget. The budget process compares the goals of the President, the Office of Science and Technology Policy (OSTP), the agencies, and Congress—not only what each seeks to achieve, but also how they plan to do so. However, no organization looks across the Federal research system to determine the framework for making choices.

From the discussion in chapter 3, one could conclude that OMB has been the surrogate for such an agent, with Congress then adding its own priorities through budget negotiations.[3] The agencies spend these appropriated sums based on strategic plans that reflect their research missions, sorting long-range from short-range investments, weighing new initiatives against "out-year" commitments (in multiyear

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[1] Doug Walgren, Chairman of the Subcommittee on Science, Research, and Technology, in U.S. Congress, House Committee on Science, Space, and Technology, *The Hearings on Adequacy, Direction, and Priorities for the American Science and Technology Effort*, 101st Cong., Feb. 28-Mar. 1, 1989 (Washington, DC: U.S. Government Printing Office, 1989), p. 1.

[2] "Outlays by Category," *Government Executive*, vol. 22, September 1990, p. 44. Furthermore, within the category of "R&D," research has seen much greater increases than development (which has decreased in constant dollars) since the late 1960s. See Lois Ember, "Bush's Science Advisor Discusses Declining Value of R&D Dollars," *Chemical & Engineering News*, vol. 68, No. 17, Apr. 23, 1990, pp. 16-17.

[3] For an overview, see Elizabeth Baldwin and Christopher T. Hill, "The Budget Process and Large-Scale Science Funding," *CRS Review*, February 1988, pp. 13-16.

Table 5-1—Summary of President Bush's $1.4 Trillion Fiscal Year 1991 Budget, Items Listed Under Theme I: Investing in the Future

Increasing saving, investment, and productivity

Expanding the human frontier
Space:
  1. Infrastructure
  2. Manned exploration (Space Station Freedom, Moon-Mars Mission)
  3. Increasing scientific understanding (global change, developing commercial potential, other)
Biotechnology
Superconducting Super Collider

Enhancing research and development
  1. Doubling the National Science Foundation budget
  2. Global change
  3. Agricultural research initiative
  4. HIV/AIDS
  5. R&D for advanced technology
  6. Magnetic levitation transportation
  7. Science and engineering education
  8. Research and experimentation tax credit
  9. R&D by transnational companies

Investing in human capital
Education:
  1. Preparing children to learn (including Head Start)
  2. Targeting resources for those most in need (including K-12, Educational Excellence Act, mathematics and science, historically Black colleges and universities)
  3. Education research and statistics
Job training
Enhancing parental choice in child care

Ending the scourge of drugs

Protecting the environment (including global climate change research)

Improving the Nation's transportation infrastructure

Bringing hope to distressed communities

Preserving national security and advancing America's interests abroad (including the Department of Defense research and technology)

Preserving America's heritage

SOURCE: "President Bush's 1991 Budget Fact Sheet," Jan. 29, 1990.

awards), and allocating resources by program, project, and performer. Even this picture is too simple, however, since many decisions involve extensive debate within the government and the public, and developments within programs and the scientific community also influence the decisionmaking process.

Congress wishes—perhaps now more than ever—that the scientific community could offer priorities at a macro level for Federal funding. However, this community has long declined to engage in priority setting, claiming a lack of methods to compare and evaluate different fields of science and desiring to maintain high levels of funding for all fields, instead of risking cuts in any particular one. It has fallen primarily to the Federal Government to set priorities, both among and within fields of science, and this situation will most likely continue through the 1990s.

In the scientific community, calls for priority setting are also often confused with calls to direct *all* research along specified lines. Even with greatly enhanced priority setting, one goal would certainly be the maintenance of funding for a diverse science research base. This priority has been preeminent since the Federal support of research began.[4] Other priorities would include training for scientists and engineers, and supplying state-of-the-art equipment. At present, the means to meet these goals are a matter of continuous debate and policy revision.

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[4] See U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, *A History of Science Policy in the United States, 1940-1985*, 99th Cong. (Washington, DC: U.S. Government Printing Office, September 1986).

In an era of greater priority setting, the Federal Government would seek to target specific goals. For instance, the allocation of additional monies to the National Institutes of Health (NIH) for AIDS research, beginning in the late 1980s and continuing to the present day, has been a clear designation of a priority research area. Future decisions may center on ranking projects designated "big science," since not all of them can be supported in the current fiscal climate. Similarly, fields that have received large increases in funding during the 1980s, such as the life sciences, may grow more slowly, as others are given precedence.

Although priority setting occurs throughout the Federal Government, it falls short in three ways. First, criteria used in selecting areas of research and megaprojects (e.g., the Superconducting Super Collider (SSC) and the Space Station) are not made explicit, and appear to vary widely. This is particularly a problem at the highest levels of priority setting, e.g., in the President's budget and the congressional decision process. Second, there is currently no formal or explicit mechanism for evaluating the total research portfolio of the Federal Government in terms of progress toward national objectives. Third, the principal criteria for selection, "scientific merit" and "mission relevance," are in practice coarse filters.

This chapter examines priority setting in the Federal research system. First, it describes the historical justification for priority setting and recent pressures stemming from budgetary constraints. Second, it reviews specific frameworks for setting priorities generated by various parts of the research system. (For a discussion of priority setting in other countries, see appendix D.) Most proposed frameworks include a distinction between "big" and "little" science, both as research strategies and as accounts with certain expectations. But definitions are murky. OTA thus discusses the criteria applied to justify investments in various categories and the decisions that generate agency research "portfolios." Finally, the use of priority setting to clarify goals, strategies, and outcomes is analyzed as part of democratic decisionmaking.[5]

Photo credit: National Aeronautics and Space Administration

Astronaut prepares experiments, which separate cells according to their electric charge, on board the Earth-orbiting Columbia Space Shuttle. The difference between big and little science is murky, in part because the advent of new large equipment (such as the Shuttle) often allows new forms of what would be called "little science" when performed in other environments.

Historical Justification for Priority Setting

Investment in research is open-ended and uncertain in outcome. Thus, Federal decisionmakers bring different expectations and justifications to making choices in research. Recognizing this, Alvin Weinberg, former Director of Oak Ridge National Laboratory, proposed over a quarter-century ago a set of "criteria of scientific choice."[6] He wrote:

> Society does not *a priori* owe the scientist, even the good scientist, support any more than it owes support to the artist or to the writer or to the musician. Science must seek its support from society on grounds other than the science is carried out competently and that it is ready for exploitation. . . . Thus, in seeking justification for the support of science, we are led inevitably to consider external criteria for the validity of science, those criteria external to science or to a given field of science.[7]

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[5] The Federal budget process plus the annual cycle of authorization and appropriations hearings allow ample opportunity for iteration—to revisit projects, check their progress, revise cost and time estimates, and so on. But this is done piecemeal. Some mechanism viewing the entire research portfolio is needed, perhaps on a different cycle than the budget. A more "ideal" Federal research portfolio could be constructed iteratively—a process which could fortify the science base while allowing for the pursuit of some, but not all, new big science initiatives.

[6] Two papers on the topic, originally published in *Minerva*, are reprinted with additional discussion in A.M. Weinberg, *Reflections on Big Science* (Cambridge, MA: MIT Press, 1966).

[7] Ibid., p. 72.

Weinberg's ''external'' criteria consist of *social merit* and *technological merit*. They declare the support of science as a priority to be judged against nonscience investments and favor the ''applied'' end of the research continuum. These criteria conjure up the potential applications and social value of scientific research. Science *for* society is epitomized by such investment criteria.

Weinberg's ''internal'' criteria, on the other hand, are those embraced by research performers and, to a lesser extent, agency sponsors. For them *scientific merit* is the prime justification for Federal support, one that ''. . . puts value on the progress of the scientific enterprise as a whole. Knowledge production is thus held to be a meritorious activity in its own right. . . .''[8] With no promised immediate benefit to society, the support of research has a more esoteric justification, such as the ''ripeness'' of a field for exploitation that will advance the state of theory or technique. The significance of this outcome may remain within a research community or be shared only by specialists in neighboring fields. For them, such developments become a priority. Making this intelligible and persuasive to those who control resources, e.g., within agencies or to one's congressional representative, however, is what may influence the policy process. A 1988 statement of the priorities issue suggests that the criteria have not changed much from Weinberg's original formulation (see box 5-A).

Historically, the notion of criteria, with scientific merit at its core, rearticulates the social contract that ties Federal research funding policies to investigators and research programs that bubble up to excite other specialists and agency sponsors. For Weinberg, ''. . . the *purest* basic science [can] be viewed as an overhead charge on the society's entire scientific and technical enterprise.''[9] This conception of research as overhead on society's near-term goals has been reasserted of late with changes in the Federal funding climate. Under the strain of demands on the Federal budget, the call for priority setting has grown louder.

The Funding Climate and Research Priorities

The 101st Congress engaged in what has been characterized as ''. . . six of the most consequential and rancorous science and technology debates.''[10] Four of these six are unambiguously research related; they are presented by Senate and House votes in table 5-2: mathematics and science education, the SSC, environmental protection, and space/National Aeronautics and Space Administration (NASA). (Note the overlap between the items listed here and in the President's priorities.) The need for trained people, sophisticated instrumentation, the reduction of risk, and continued exploration of space reflect the relation of science and technology to the Nation's total market basket of investments.

> Even though R&D still sit in the vulnerable corner of the budget that carries the label of ''discretionary'' spending, it's clear that science and technology no longer are viewed as flip-of-the-coin judgment calls. Rather, they are now seen as necessary and strategic obligations tied to national needs, and no matter how awful the budget deficit looks, R&D will get better relative consideration than anything else in the discretionary sector. . . . [11]

However, under tight fiscal conditions, no part of the budget may fare well. As Association of American Universities President Robert Rosenzweig states:

> Another thing that concerns me . . . is the dynamic that seems to be set up by the next three to five years of budget problems. We're going to be fighting among ourselves a lot—universities and elements within universities. . . . The domestic discretionary [budget] pool . . . is not supposed to grow for the next five years, save for inflationary increases. But

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[8] John Ziman, *An Introduction to Science Studies* (New York, NY: Cambridge University Press, 1984), p. 163.

[9] Weinberg, op. cit., footnote 6, pp. 97-99. Also see Harvey Brooks, ''Models for Science Planning,'' *Public Administration Review*, vol. 31, May/June 1971.

[10] Wade Roush, ''Science and Technology in the 101st Congress,'' *Technology Review*, vol. 93, No. 8, November-December 1990, p. 59. These six differed slightly in the House and Senate, and two—having to do with the Clean Air Act and the B-2 Stealth Bomber—have arguably little science content.

[11] William D. Carey, ''R&D in the Federal Budget: 1976-1990,'' *Science and Technology and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), p. 48.

Box 5-A—A Statement From the Scientific Community on the Evaluation of Competing Scientific Initiatives

The following criteria were proposed in 1988 for evaluating competing scientific initiatives. They are presented here (in abridged form) in the three categories developed by the authors.[1]

Scientific Merit

1. Scientific objective and significance
   Example: What are the key scientific issues addressed by the initiative?
2. Breadth of interest
   Examples: Why is the initiative important or critical to the discipline proposing it? What impact will the science involved have on other disciplines?
3. Potential for new discoveries and understanding
   Examples: Will the initiative provide powerful new techniques for probing nature? What advances beyond previous measurements can be expected with respect to accuracy, sensitivity, comprehensiveness, and spectral or dynamic range? In what ways will the initiative advance the understanding of widely occurring natural processes and stimulate modeling and theoretical description of these processes?
4. Uniqueness
   Example: What are the special reasons for proposing this initiative? Could the desired knowledge be obtained in other ways? Is a special time schedule necessary for performing the initiative?

Social Benefits

1. Contribution to scientific awareness or improvement of the human condition
   Examples: Are the goals of the initiative related to broader public objectives such as human welfare, economic growth, or national security? Will the results assist in planning for the future? What is the potential for stimulating technological developments that have application beyond this particular initiative? Will the initiative contribute to public understanding of the goals and accomplishments of science?
2. Contribution to international understanding
   Example: Will the initiative contribute to international collaboration and understanding?
3. Contribution to national pride and prestige
   Example: Will the initiative create public pride because of the magnitude of the challenge, the excitement of the endeavor, or the nature of the results?

Programmatic Concerns

1. Feasibility and readiness
   Examples: Is the initiative technologically feasible? Are there adequate plans and facilities to receive, process, analyze, store, distribute, and use data at the expected rate of acquisition?
2. Scientific logistics and infrastructure
   Examples: What are the long-term requirements for special facilities or field operations? What current and long-term infrastructure is required to support the initiative and the processing and analysis of data?
3. Community commitment and readiness
   Example: In what ways will the scientific community participate in the operation of the initiative and the analysis of the results?
4. Institutional implications
   Examples: In what ways will the initiative stimulate research and education? What opportunities and challenges will the initiative present for universities, Federal laboratories, and industrial contractors? What will be the impact of the initiative on federally sponsored science? Can some current activities be curtailed if the initiative is successful?
5. International involvement
   Example: Are there commitments for programmatic support from other nations or international organizations?
6. Cost of the proposed initiative
   Examples: What are the total costs, by year, to the Federal budget? What portion of the total costs will be borne by other nations?

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[1] Adapted from John A. Dutton and Lawson Crowe, "Setting Priorities Among Scientific Initiatives," *American Scientist*, vol. 76, November-December 1988, pp. 600-601.

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Table 5-2—Favorable Senate and House Votes on Science Issues in the 101st Congress

Senate votes

Mathematics and science education programs: S. 695, President Bush's "Excellence in Education Act," includes $5 million for a national Science Scholars program. Passed 92-8 on Feb. 7, 1990; R 37-8, D 55-0.[a]

Superconducting Super Collider authorization: H.R. 5019 appropriates $20.8 billion for energy and water programs, including $318 million for the accelerator. Passed by voice vote on Aug. 2, 1990.

Technology programs authorization: S. 1191 authorizes $320 million in fiscal year 1990 funds for research on high-definition television and other new technologies through the Advanced Technology Program of the National Institute of Standards and Technology. Passed by voice vote on Oct. 26, 1989.

House votes

Superconducting Super Collider authorization: H.R. 4380 limits Federal spending on the advanced atom smasher to $5 billion, with $2.4 billion more to come from Texas and foreign sources. Passed 309-109 on May 2, 1990; R 115-57, D 194-52.

Mathematics and Science Education amendments: H.R. 5115 authorizes $1.1 billion in fiscal years 1991 to 1995 for congressional science scholarships and other education reforms. Passed 350-25 on July 20, 1990; R 123-25, D 227-0.

Technology programs authorization: H.R. 4329 funds the National Institute of Standards and Technology through 1992, including $100 million in fiscal year 1991 and $250 million in fiscal year 1992 for research on high-definition television and other new technologies under the Advanced Technology Program. Passed 327-93 on July 11, 1990; R 83-90, D 244-3.

National Aeronautics and Space Administration funding: H.R. 5158 appropriates $14.3 billion for NASA. Passed 355-48 on June 28, 1990; R 128-39, D 227-9.

KEY: R=Republicans; D=Democrats; NASA=National Aeronautics and Space Administration.

[a] Both the House and the Senate passed the Excellence in Mathematics, Science, and Engineering Act of 1990 (Public Law 101-589) in October 1990, and $149 million was appropriated.

SOURCE: Based on Wade Roush, "Science and Technology in the 101st Congress," *Technology Review*, vol. 93, No. 8, November-December 1990, p. 65.

> everybody is going to be out to get more money. They all feel that they deserve and need more money, and they're probably right.[12]

These commentators, speaking 2 years after National Academy of Sciences (NAS) President Frank Press warned of constrained research budgets as ''the dilemma of the golden age,''[13] suggest some accommodation to this reality: while the Federal Government could invest more in science and technology, the scientific community could do a better job of sorting research opportunities by whatever criteria chosen to assist decisionmakers at all levels of the system.

Science Advisor Bromley and Former Science Advisor Press have stated criteria and categories of priority that they consider essential for science, listed in table 5-3. (Projects are compared under each category to compete for monies allocated within that category.) Note the convergence between the Science Advisor's (OSTP/OMB's) and the NAS President's (and former Science Advisor's) formulations. Each emphasizes the separation of large projects requiring new infrastructure from ''small science.'' Press distinguishes human resources from national crises and extraordinary scientific breakthroughs in his primary category. Bromley places national political exigencies above all else,[14] whereas Press prefers to put these items into a ''political category'' of third priority. One effect of these rank orders is the seeming creation of separate accounts, i.e., that choices could be made within each category and then across categories.[15] Of course, such choices are being made by various participants in the research

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[12] Quoted in ''A Good Budget for Science, But Troubles Lie Ahead,'' *Science & Government Report*, vol. 20, No. 18, Nov. 15, 1990, pp. 1, 4. In the President's proposed fiscal year 1992 budget, civilian R&D spending would rise 13 percent to $76 billion, with basic science increasing 8 percent to $13 billion. See William Booth, ''President Puts Fiscal Faith in Science,'' *The Washington Post*, Feb. 13, 1991, p. A17. Also see Jeffrey Mervis, ''Bush's Science Budget: Will It Hold?'' *The Scientist*, vol. 5, No. 5, Mar. 4, 1991, pp. 1, 6-7.

[13] Frank Press, ''The Dilemma of the Golden Age,'' *Congressional Record*, May 26, 1988, pp. E1738-E1740. Press's categories and priorities are presented below.

[14] Bromley's statement was augmented in September 1990 by a brief Office of Science and Technology Policy document, ''U.S. Technology Policy.'' The document serves to bridge the roles of the private sector and the Federal Government in research and development. Justifications for the President's fiscal 1991 budget requests for ''education and training'' and ''Federal R&D responsibilities'' are presented by agency in addition to discussion of federally funded technology transfer and Federal-State activities. See Executive Office of the President, Office of Science and Technology Policy, ''U.S. Technology Policy,'' unpublished document, Sept. 26, 1990.

[15] Note that scientific merit is *assumed* in both formulations and not explicitly stated as a funding criterion. The issue becomes one of first ranking science projects according to scientific merit and then assigning them to national goal categories, or alternatively starting from a national goal and organizing a research strategy to meet it.

Table 5-3—Two Statements on Research Priorities

Source	Criteria	Categories in rank order
Bromley	". . . guiding principles on prioritizing the agency requests . . ."	1. National needs and international security concerns (global change, preeminence in space, defense technology base). 2. Support for basic research (particularly university-based, individual-investigator and small-group research—"small science"). 3. Funding for scientific infrastructure and facilities (SSC, Space Station, and ". . . in a more distilled sense . . ." Human Genome).
Press	". . . appropriate for the unprecedented Federal deficit . . ." and ". . . to maintain American leadership in science and technology . . ."	1. Human resources, national crises (AIDS, space launch capacity), extraordinary scientific breakthroughs (high-temperature superconductivity). 2. Large projects (SSC, Human Genome). 3. Political category (DOD and national security; Space Station; regional economic development and employment; U.S. image enhancers like manned space flight; U.S. "competitiveness" enhancers like education, training, and civil sector R&D).

KEY: SSC=Superconducting Super Collider; DOD=U.S. Department of Defense.

SOURCES: D. Allan Bromley, "Keynote Address" *Science and Technology and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S. L. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), p. 11. Also see "Q&A With D. Allan Bromley, Bush's Science Advisor," *Science & Government Report*, vol. 20, June 1, 1990, p. 5; and Frank Press, "The Dilemma of the Golden Age," *Congressional Record*, May 26, 1988, pp. E1738-E1740.

system simultaneously. The congressional budget process may be the final arbiter, but even after Federal monies are obligated, choices at the agency and program levels occur.

In addition to supporting meritorious research, most Federal research agencies would embrace the following as relevant to their mission:[16]

- to provide fiscal support to the research system (both the infrastructure needed to conduct research and the research itself);
- to invest in human capital today (i.e., the research work force) and tomorrow (i.e., student apprentices);
- to sustain the performance sector of research (especially the research universities) and to build institutional capacity (especially as viewed by region or State); and
- as a factor in economic development and the application of research to solving local problems.

Clearly, not every program in every research agency can apply these as funding criteria without compromising any single one.

In response to a congressional request in 1988, NAS also devised a framework for thinking about Federal science and technology budget priorities. The result is presented in table 5-4. In this four-category scheme, ''agency budgets and missions'' are viewed as separate from needs of the ''science and technology (S&T) base,'' ''national [political] objectives,'' and ''major S&T initiatives.'' All are illustrated by NAS at the agency level, listing the following needs: educating science and engineering personnel; modernizing equipment and facilities; supporting a mix of basic and applied research; capitalizing on promising new research opportunities; promoting interactions between related fields of science and engineering research; distributing research support by geographic region and type of institution; maintaining a mix of research modes, e.g., individual investigators, large groups, centers, and university-industry partnerships; and balancing competitiveness and cooperation with research programs in other countries.[17]

If these items were interpreted as listed in *order of importance*, top to bottom, the projects funded by the research agencies (indeed, the proposals received) might look quite different from the research projects currently supported. Priorities can perturb the funding system; they can redefine the ''haves'' and ''have nots'' (e.g., institutions, fields, investigators) by changing the value of certain criteria. For instance, some agency funding decisions signal that a premium has been placed on other needs (see box 5-B).

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[16] OTA interviews at the Federal research agencies, spring-summer 1990.

[17] National Academy of Sciences, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures*, a report in response to the Conference Report on the Concurrent Resolution on the Budget for Fiscal Year 1989 (H. Con. Res. 268) (Washington, DC: National Academy Press, 1988), p. 10.

Table 5-4—Framework for Assessing Science and Technology Budgets (categories are not mutually exclusive)

Category	Definitions	Examples
Agency budgets and missions	Agency S&T activities viewed in terms of their contributions to individual agency goals and objectives	Nuclear alternative energy R&D in DOE Submarine acoustics in DOD Cell biology in HHS Influence on learning in ED Plant disease resistance in USDA Fundamental research in chemistry in NSF Standards development in NIST Aeronautical research in NASA
S&T base	Activities that provide the people knowledge, and infrastructure to carry out S&T Activities supported across many agencies and under the jurisdiction of several congressional committees	Basic and applied research programs in NSF, HHS, DOD, DOE, NASA, USDA, EPA, etc. Student fellowships in ED, NSF, HHS, DOD, DOE, NASA, etc. Equipment and instrumentation programs in HHS, DOE, NSF, USDA, NASA, DOD, etc. Facilities for research, animal care, and growing and using special materials supported by NSF, DOD, HHS, DOE, NASA, etc. K-12 materials development in NSF, ED, NASA, etc. Student internships in Federal laboratories in DOE, NIH, etc.
S&T applied to national objectives (Presidential and congressional priorities)	Stated priorities of the President and Congress with major S&T components Frequently supported by several agencies and within the purview of several congressional committees	Understanding and ameliorating global change in EPA, DOE, NSF, NASA, USDA, NOAA, etc. Industrial development in biotechnology, superconductivity, manufacturing technologies in HHS, DOD, Commerce, NASA, NSF, DOE, USDA, etc. Alternative sources of energy in DOE, NSF, DOD, USDA, etc. AIDS in HHS, ED, DOD, State Department, etc. Creation of nuclear defense (Strategic Defense Initiative in DOD) Increase capacity for exploration of space (Space Station in NASA)
Major S&T initiatives	Significant increase (and sometimes decreases) in budgets over several years Budgetary consequences across agencies Fall in one or more of above three categories	Superconducting Super Collider Mapping and sequencing the human genome Space Station

KEY: DOD=U.S. Department of Defense; DOE=U.S. Department of Energy; ED=U.S. Department of Education; EPA=U.S. Environmental Protection Agency; HHS=U.S. Department of Health and Human Services; NASA=National Aeronautics and Space Administration; NIH=National Institutes of Health; NIST=National Institute of Standards and Technology; NOAA=National Oceanic and Atmospheric Administration; NSF=National Science Foundation; R&D=research and development; S&T=science and technology; USDA=U.S. Department of Agriculture.

SOURCE: National Academy of Sciences, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures* (Washington, DC: National Academy Press, 1988), table 1, p. 7.

Concern for the S&T base closely approximates the needs of research. In the words of the NAS report:

> The S&T base is the bedrock of the Nation's ability to use science and technology in the national interest and . . . it requires continual replenishment. Continuity does not imply steady funding of the same activities and institutions through the same programs and agencies year after year. On the contrary, the enterprise ought to be highly dynamic. Policymakers must be able to respond flexibly to scientific breakthroughs that suddenly transform an area of research (e.g., high-temperature superconductivity), the invention of a powerful new instrument (e.g., gene-sequencing machine) or conceptions of new facilities that would aid research and training (e.g., supercomputer centers and networks), unexpected shortages of science and engineering personnel, or changing institutional relationships (e.g., the emergence of university-industry research partnerships). And as if that were not a sufficient challenge, budget makers and analysts must be attuned to differences among a wide range of fields. Some changes affect many disciplines, others only a part of a single discipline.[18]

Frameworks such as OSTP's and NAS's help to demarcate the tradeoffs that could be made and assist decisionmakers to understand that priority setting is a dynamic process. Priorities change with goals. As Weinberg put it:

> . . . we cannot evaluate a universe of scientific discourse by criteria that arise solely from within that universe. Rather, we find that to make a value

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[18] Ibid., p. 5.

Box 5-B—Criteria for Awarding a Magnet Research Laboratory: NSF, Florida State, and MIT

In August 1990, the National Science Board (NSB) of the National Science Foundation (NSF), decided to award a $60-million grant to Florida State University to establish a national laboratory for magnet research. Then-NSF Director Erich Bloch admitted that peer reviewers had found the proposal from the Massachusetts Institute of Technology (MIT), home of the Francis Bitter National Magnet Laboratory, "technically superlative," but cited the greater "enthusiasm" of the Florida investigators, the State of Florida's pledge to contribute $58 million, and other factors in funding the Florida proposal.[1]

The issues involved in the NSF decision are many. At one level, the award is evidence that scientific merit is not enough to guarantee success in competition for a facility where there can be only one winner.[2] NSF cited as decisive the superior "management plan" in the Florida proposal. Clearly, the message being sent—part of Bloch's larger emphasis on centers and government-industry partnerships to enhance U.S. economic competitiveness—was the rules of the game are changing: criteria other than technical merit are weighed in determining qualification to manage and execute a multiyear research program requiring the expertise of investigators from various institutions.[3]

In the magnet laboratory competition, the commitment of MIT was found wanting. According to NSF Assistant Director David A. Sanchez: ". . . you need support from the institution, you need support from the State, and we did not see that . . ." from MIT.[4] NSB concurred.

The MIT protest of Florida State's selection was not limited to NSF's decision to overrule its reviewers' recommendations. MIT President Paul Gray appealed on several grounds. First, the delay caused by construction of the Florida State facility ". . . is hardly compatible with NSF's interest in the competitive posture of the United States." Second, some fear that projects with significant State support, so-called leveraging of Federal funding, will put private universities at a disadvantage. Third, expertise in the Florida State physics department may be lacking.[5]

Consider, too, the symbolism of the decision. As one columnist put it: "So maybe the mandarins from MIT got caught napping. Maybe. Or maybe not."[6] MIT epitomizes the Northeast science establishment.[7] The Southeast is, in a sense, an underutilized region for research. Awards such as the magnet laboratory signify that, in specific cases, institutional collaborations can make a State or region competitive for Federal research funding.

Such awards build research capability almost from the ground up; they are a capital investment that diversifies research performers—with short- and long-term consequences for the research community and the Nation. Decisions such as this one also call for evaluation: what happens to magnet research while the Florida State facility is being constructed? Will the State of Florida deliver on its pledges? And is there any impact on the competitiveness of U.S. researchers in fields that use powerful magnets, such as superconductivity and magnetic-resonance imaging?

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[1] See Goldie Blumenstyk, "Science Agency Picks Florida State Over MIT as Site for $60-Million Magnet-Study Lab," *The Chronicle of Higher Education*, vol. 37, No. 1, Sept. 5, 1990, p. A21.

[2] The award of a 5-year, $25 million earthquake project to a consortium centered at the State University of New York at Buffalo sent a similar signal to Caltech and a California consortium in 1987. It also led to a General Accounting Office (GAO) investigation of the National Science Foundation (NSF) review process that sanctioned the award. While it sustained the fairness of the NSF process, it did question its documentation procedures. See U.S. General Accounting Office, *National Science Foundation: Problems Found in Decision Process for Awarding Earthquake Center*, GAO/RCED-87-146 (Washington, DC: June 1987).

[3] Florida State is to be joined by the University of Florida and Los Alamos National Laboratory in New Mexico in making the magnet laboratory a reality.

[4] In Blumenstyk, op. cit., footnote 1, p. A22. National Science Foundation reviewers said the Massachusetts Institute of Technology's "decaying plant" would require substantial modernization. The institution will submit a proposal for further support until the Florida State laboratory begins operations in 1993.

[5] All of these plus criticism of the National Science Board (especially the lack of "working scientists" among its members) are cited by a trio of Princeton physicists in Philip W. Anderson et al., "NSF Magnet Lab," letter, *The Scientist*, vol. 4, No. 23, Nov. 26, 1990, p. 14. The Florida State proposal included a pledge from the State ". . . to add 24 new faculty members and 10 laboratory experts and to provide 20 annual fellowships for visiting scientists from around the world."

[6] David Warsh, "Will Florida Become a New Bastion of Industrial Science?" *The Washington Post*, Sept. 12, 1990, p. C3.

[7] The Massachusetts Institute of Technology consortium was to include Boston, Brandeis, Harvard, Northeastern, and Tufts universities.

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Photo credit: National Aeronautics and Space Administration

Researcher studies magnetic liquids. In this example of little science, the research is supported by the National Aeronautics and Space Administration.

> judgment, we must view the enterprise from a broader point of view than is afforded by the universe itself. . . . And so it is with the rest of science. The scientific merit of a field must be judged in large part by the contribution it makes, by the illumination it affords, and by the cohesion it produces in the neighboring fields.[19]

Leaders of the scientific community have subscribed to the need for something other than ad hoc policymaking for research funding. OTA next examines the problems inherent in two categories of this funding—the science base and science megaprojects.

The Science Base

Little science is the backbone of the scientific enterprise, and a diversity of research programs abounds. For those who believe that scientific discoveries are unpredictable, supporting many creative researchers who contribute to S&T, or the science base, is prudent science policy. In the words of one geographer: "The continued survival of our intellectual free market is important to scientific progress."[20] Not surprisingly, many investigators and their teams shudder at the thought of organizing Federal research funding around a principle other than scientific merit. They fear that setting priorities would change the criteria by which research funds are awarded.[21] They would run the risk of losing what they consider their fair market share. Does priority setting necessarily curb the search for new knowledge, or just redirect it?

Consider the research portfolios of the Federal Government. As shown in figure 5-1, broad field funding, 1969 to 1990, has favored the life sciences, almost doubling in constant dollars during that period. Mathematics/computer, physical, and environmental sciences have also increased; engineering has remained stable in funding; and social sciences have decreased. In retrospect, should these be decried as less than rational choices? With a change in the Federal funding environment, should the ground rules for allocating resources among broad fields and performers also change? And what role can peer review play?

Peer Review and Priority Setting Across Broad Fields

Peer review is used in a variety of ways within the Federal agencies. As seen in chapter 4, only a few agencies, primarily the National Science Foundation (NSF) and NIH, employ peer review throughout their priority-setting and funding allocation processes. At NSF and NIH, peer review is considered to be:

- effective for communicating expert opinion about what proposals definitely should and should not be funded (and the large gray area in between) within a narrow band of specialization corresponding to the scope of an agency program;

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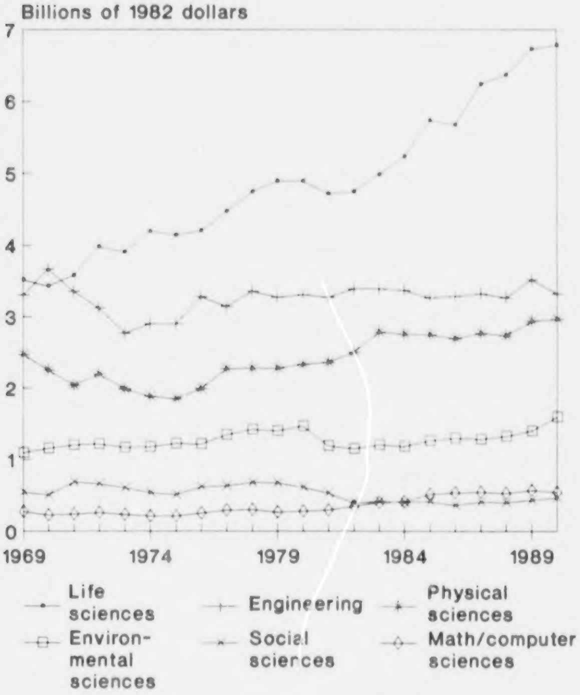
[19] Weinberg, op. cit., footnote 6, p. 116.

[20] G. Robert Brakenridge, "Evaluating Scientific Initiatives," letter, *American Scientist*, vol. 77, No. 3, May-June 1990, p. 213.

[21] They also seem to confuse strategy (*what* to do) with tactics (*how* to do it). Criteria correspond to strategies, while project selection methods (e.g., peer review) represent tactics or ways to identify research that helps achieve stated priorities.

Figure 5-1—Federally Funded Research by Broad Field: Fiscal Years 1969-90
(in billions of constant 1982 dollars)



NOTE: Research includes both basic and applied. Fields not included in this figure collectively accounted for $1.1 billion (4.9 percent) of all federally funded research in 1990. Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table 25; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1.

- efficient, in terms of the time, money, and energy involved in the process of deciding how resources should be allocated; and
- accountable, ensuring that the highest standards of rigor (valid and reliable measurement), safety (for animals, human subjects, and laboratory personnel), and freedom (e.g., to follow hunches, train students, and exchange data) in research are observed.

In sum, peer review is expected to be robust and responsive to changing agency and program needs. Satisfying all of these criteria simultaneously, however, is difficult at best (see box 5-C) and, in practice, a compromise is struck between them.

Federal monies awarded to researchers for some expressed purpose other than or in addition to "scientific merit" are seen by many as inferior to monies for projects selected by peer review processes using scientific merit alone. Some are inclined to the view that there is something inherently wrong with such "political allocations." The policy issue is whether peer review can simultaneously serve to discern scientific merit *and* help in project-based priority setting.

Reviewing for "truth," as science policy statesman Harvey Brooks writes, differs from reviewing for "utility." Peer scientists are not very helpful with the latter.[22] In Weinberg's terms, criteria of scientific merit clash with criteria of social or technological merit. Peer review as a tactic tends to break down when confronted with incommensurate information from competing disciplines, fields, or projects. As two commentators ask:

> Should peer review operate only to evaluate merit or should it also help establish priorities? Can it or should it be effective in changing the direction of a program, in allocating resources among programs within agencies themselves? These questions are significant because they challenge the assumption that peer review is the best possible way to allocate resources in the best overall interests of both science and society.[23]

Recognizing the limits of specialization, agencies maximize expertise in subject-focused programs. Specialists are quite well-suited to the task of making quality distinctions within disciplinary or problem-centered boundaries. But discriminations that must cross boundaries, no longer comparing like with like, are rarely ever accomplished by peer review, since reviewers in one field are very reluctant to judge the scientific or technical merits of information from other fields. There are no rules inside the scientific enterprise that suggest that one kind of information is superior to another. The

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[22] Harvey Brooks, "The Problem of Research Priorities," *Daedalus*, vol. 107, No. 2, spring 1978, pp. 171-190.

[23] Richard C. Atkinson and William A. Blanpied, "Peer Review and the Public Interest," *Issues in Science & Technology*, vol. 2, summer 1985, p. 110.

Box 5-C—Peer Review in Changing Environments: Remarks at a Roundtable Discussion

In June 1990, the Forum on Research Management (FORM), consisting in equal parts of program officers from the behavioral science divisions of various Federal agencies and of senior researchers and research managers from academia and the private sector, met to discuss peer review.[1] Two dozen FORM members discussed some of the pros and cons of peer review in an era of fiscal austerity. Their positions as agency administrators faced with allocation decisions, as lobbyists surveying the funding scene, and as researchers competing for scarce program dollars give them an acute sensitivity to proposal review and the environments in which it is carried out. The remarks are as verbatim as the edited transcription allowed. Each bulleted item represents a different speaker.

- There is a connection . . . between tight funding and peer review. As money gets tighter, peer reviewers become more conservative, less prone to take risks.
- What they [peer reviewers] are doing is giving higher and higher ratings, which in effect increases the noise in the system. So the peer review system is calling more proposals "excellent" and "outstanding," and the consequence is that it is very difficult for program managers to make evaluations. What results is a beauty contest or just chance.
- Has the science changed? Has the quality of the proposals changed? I think the answer to both questions is yes. . . . Peer reviewers used to be tightly knit groups examining proposals from people they knew extremely well—it was a very closed society. Now it is a much more complicated task.
- Would it really be valuable to have a peer review system and an amount of money where everything was funded? I suspect it may lead to very bad science.
- There are two things going on in peer review—one is selection, which is important, but the other is education (of the proposer and reviewer). I think the latter function sometimes gets lost. Unfortunately, crushing workloads are reducing the educational function of peer review.
- When I serve on a [National Institutes of Health] study section, I find it extremely disconcerting and distracting to be told by program people about what percentage of the applications are likely to be funded. It distorts my entire approach, as well as that of my colleagues. For instance, if we're told only 10 percent are likely to be funded, we start playing with the ratings to ensure certain results.
- Study sections are not supposed to be making funding decisions. They are to make scientific recommendations. There should be recognition that there are two discrete sets of staff used in NIH peer review. . . . Priority scores do not determine funding. That's what advisory councils and institute directors are for.
- People are increasingly reluctant to get involved [in peer review]. . . . I wonder if we are losing certain types of reviewers from the process—not just to get women and minorities on the panels—with increasing demands on time.

These observations illustrate the challenges posed by competition and resource scarcity. Other challenges include the consequences of age and prestige on the allocation of Federal funds, the fate of proposals that cross disciplines and fall between agency programs, and the psychology of collective decisionmaking.[2] Debate on the burdens absorbed by Federal peer review systems is healthy if it informs the practices of agencies, investigators, and reviewers.

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[1] The Forum on Research Management was created in 1982 as a working group of the nonprofit Federation of Behavioral, Psychological, and Cognitive Sciences. Most of the attendees at the meeting were from the National Science Foundation, the National Institutes of Health, and a few professional associations headquartered in Washington, DC. The excerpts below are based on a transcript of the meeting supplied by David Johnson, executive director of the Federation.

[2] Some of these have been addressed empirically. See the special issue, "Peer Review and Public Policy," *Science, Technology, & Human Values*, vol. 10, No. 3, summer 1985, pp. 3-86.

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Photo credit: U.S. Department of Agriculture

This type of flea beetle is one of several studied by the Department of Agriculture to combat weeds. Research on animals and weeds is very different from research on space exploration, and expert judgments require specialized knowledge.

existence of such rules would imply that information from different fields could be made commensurable.[24]

Peer review thus cannot help to set priorities beyond the limits imposed by agency organization. Whereas priorities and resource allocations for megaprojects are usually set by a tacit bargaining and lobbying process, the science base is governed by another dynamic altogether. As agencies evaluate their research needs and modify the emphases of their programs, research performers are intimately involved. But seldom does a research community coalesce around a single agenda (for an exception, see box 5-D).

The Dilemma of Agency Priority Setting

Universities or States can be analyzed as aggregate categories that receive Federal research monies, and agencies as the source of those sponsored funds. But the actual funding decisions are made in different agency programs and the research performance occurs in laboratories and departments.[25] Decisions are thus made at several levels. Priorities that originate outside the agencies as "national goals" do not simply trickle down; they are adapted to what may be called an agency research portfolio, which in turn is comprised of various program portfolios ("funding strategies"). Within these organizational niches, priorities are set all the time. Thus, agencies may have the discretion to pursue certain national needs by applying a different or reordered set of criteria to the selection of research performers.

Because disciplines tend to overlap agencies, priorities in physics, for example, can be set within an agency, but not readily across agencies. There is simply no routine mechanism for doing so. Physics research is distributed across three mission agencies plus NSF. While high-energy physics is supported primarily by the Department of Energy (DOE) and astrophysics by NASA, theoretical physics "belongs" to no single agency.[26] This is even more dramatically apparent in the case of neuroscience. Congress and the President declared the 1990s the "Decade of the Brain."[27] As seen in figure 5-2, the Federal Government supports neuroscience research in 6 institutes of NIH; in 3 within the Alcohol, Drug Abuse, and Mental Health Administration; and in 10 other agencies, with the National Institute of Neurological Disorders and Stroke and the National Institute of Mental Health leading the way. Unless a "lead" agency is recognized by all participants (as in computer science, see box 5-E) or an OSTP Federal Coordinating Council for Science, Engi-

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[24] That is, although some agencies use peer panels that rate multiple proposals and make direct comparisons of proposed work in their field, they do not compare their findings with those of panels in other fields, since between-field information is held to be incommensurable. Instead, they judge the technical merit of a research design, the competence of the investigators, and the institutional infrastructure available for executing the proposed design. As Harvey Brooks points out, who is the best judge of social merit? There are no experts on social merit, which has to be a collective decision involving several different kinds of expertise as well as generalists' political judgments. Personal communication, February 1991.

[25] For example, see National Science Foundation, "Planning and Priority-Setting in the National Science Foundation," a report to the Committee on Science, Space, and Technology of the U.S. House of Representatives, Feb. 28, 1990.

[26] See, for example, Sebastian Doniach, "Condensed Matter Theory's Fragile Funding," letter, *Physics Today*, November 1990, pp. 13, 117.

[27] Elizabeth Pennisi and Diana Morgan, " 'Brain Decade' Neuroscientists Court Support," *The Scientist*, vol. 4, No. 21, Oct. 29, 1990, pp. 1, 8.

Box 5-D—Priority Setting by the Ecological Research Community

In fall 1990, the Ecological Society of America proposed the Sustainable Biosphere Initiative (SBI), a research initiative that focuses on the necessary role of ecological science in the wise management of Earth's resources and the maintenance of Earth's life support systems.[1] The process of developing the research agenda affirms that a community can set priorities.[2] The document was intended as a call-to-arms for all ecologists. It was also to serve as a means of communication with individuals in other disciplines with whom ecologists must join forces. Many of the environmental problems that challenge human society are fundamentally ecological in nature.

In response to national and international needs, the SBI represents a framework for the acquisition, dissemination, and utilization of ecological knowledge in support of efforts to ensure the sustainability of the biosphere. The SBI calls for: 1) basic research for the acquisition of ecological knowledge, 2) communication of that knowledge to citizens, and 3) incorporation of that knowledge into policy and management decisions.

Research Priorities

The criteria used to evaluate research priorities were: 1) the potential to contribute to fundamental ecological knowledge, and 2) the potential to respond to major human concerns about the sustainability of the biosphere. Based on these criteria, the SBI proposes three research priorities:

1. *global change*, including the ecological causes and consequences of changes in climate; in atmospheric, soil, and water chemistry (including pollutants); and in land- and water-use patterns;
2. *biological diversity*, including natural and anthropogenic changes in patterns of genetic, species, and habitat diversity; ecological determinants and consequences of diversity; the conservation of rare and declining species; and the effects of global and regional change on biological diversity; and
3. *sustainable ecological systems*, including the definition and detection of stress in natural and managed ecological systems; the restoration of damaged systems; the management of sustainable ecological systems; the role of pests and pathogens; the transmission of disease among humans; and the interface between ecological processes and human social systems.

Existing national and international initiatives address parts of the first two priorities. Success of these programs will require increased emphasis on key ecological topics. The SBI proposes three research recommendations:

1. Greater attention should be devoted to examining the ways that ecological complexity controls global processes.
2. New research efforts should address both the importance of biological diversity in controlling ecological processes and the role that ecological processes play in shaping patterns of diversity at different scales of time and space.
3. A major new integrated program of research on the sustainability of ecological systems should be established. This program would focus on understanding the underlying ecological processes in natural and human-dominated ecosystems in order to prescribe restoration and management strategies that would enhance the sustainability of the Earth's ecological systems.

Implementation

Successful implementation of the SBI will require new interdisciplinary relationships that link ecologists with the broad scientific community, with mass media and educational organizations, and with policymakers and resource managers in all sectors of society.

> In sum, while the goals and action items of the Sustainable Biosphere Initiative may not seem revolutionary, few ecologists would have accepted them even a decade ago. But times have changed and so has the science. The public is more aware of environmental issues than ever before, and opportunities for ecologists have never been greater.[3]

Such statements are rare.[4] When they do appear, they can supply to policymakers an unusual tool for judging a hierarchy of research emphases and perhaps channeling resources to agencies and programs accordingly.

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[1] The following is based on Jane Lubchenco et al., Ecological Society of America, ''The Sustainable Biosphere Initiative: An Ecological Research Agenda,'' draft document, Oct. 30, 1990.

[2] For details on the fragile process by which the Society's 2,000 members and its leaders reached consensus, see Elizabeth Pennisi, ''Ecology Society Reaches Rare Consensus on Research Agenda,'' *The Scientist*, vol. 4, No. 17, Sept. 3, 1990, pp. 3, 9, 20.

[3] Ibid., p. 3.

[4] To take another example, the astronomy community, working through the National Academy of Sciences, has issued four decanal surveys of the field. For the latest, see National Academy of Sciences, *A Decade of Discovery in Astronomy and Astrophysics* (Washington, DC: National Academy Press, 1991); and the statement of the study committee chairman, John N. Bahcall, ''Prioritizing Scientific Initiatives,'' *Science*, vol. 251, Mar. 22, 1991, pp. 1412-1413.

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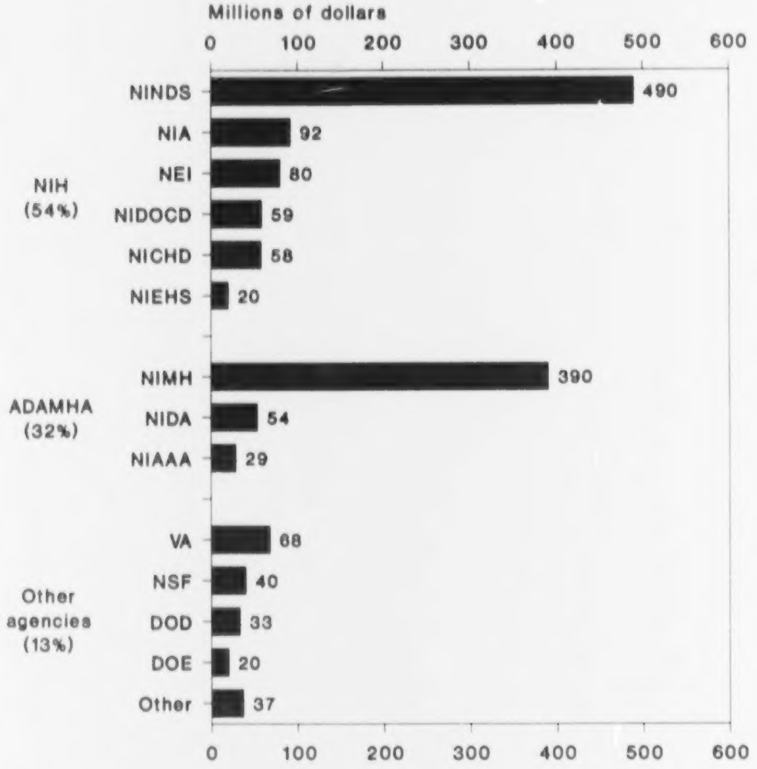
Figure 5-2—Distribution of Federal Support of Neuroscience Research: Fiscal Year 1990



KEY: NIH=National Institutes of Health; ADAMHA=Alcohol, Drug Abuse, and Mental Health Administration; NINDS=National Institute of Neurological Disorders and Stroke; NIA=National Institute on Aging; NEI=National Eye Institute; NIDOCD=National Institute on Deafness and Other Communication Disorders; NICHD=National Institute on Child Health and Human Development; NIEHS=National Institute of Environmental Health Sciences; NIMH=National Institute of Mental Health; NIDA=National Institute on Drug Abuse; NIAAA=National Institute on Alcohol Abuse and Alcoholism; VA=U.S. Department of Veterans Affairs; NSF=National Science Foundation; DOD=U.S. Department of Defense; DOE=U.S. Department of Energy; Other=National Institute on Disability and Rehabilitation Research, National Aeronautics and Space Administration, Environmental Protection Agency, U.S. Department of Agriculture, Centers for Disease Control, and Food and Drug Administration.

SOURCE: Office of Technology Assessment, based on estimates in Elizabeth Pennisi and Diana Morgan, " 'Brain Decade' Neuroscientists Court Support," *The Scientist*, vol. 4, No. 21, Oct. 29, 1990, p. 6.

neering, and Technology committee is constituted to coordinate among relevant funding organizations, aligning scientific priorities with budgets would be unlikely.

At the program level, few projects will influence the trajectories of science one way or another. A question, then, is whether agency administrators can select streams of projects, or portfolios, that result collectively in new knowledge (i.e., having reasonable technical merit) or produce social and economic benefits beyond costs.[28] Put another way, funding research can be compared to placing money in the stock market. The more diverse and strong one's portfolio of accounts, the greater the chance of

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[28] The following is based on Harvey Averch, "Analyzing the Costs of Federal Research," OTA contractor report, August 1990. Available through the National Technical Information Service, see app. F.

Box 5-E—Federal Investment in Computer Science

Since 1976, the Federal Government has had a stellar record of support for academic computer science. Funding has grown faster than for any other scientific discipline in the United States. However, support for computer science *basic* research has declined. As a consequence, questions are being raised about the amount of Federal support for computer science and the manner in which it is being distributed. A forthcoming Association for Computing Machinery (ACM) report on a 3-year study, *A Field in Transition: Current Trends and Issues in the Funding of Academic Computer Science Research*, can be viewed as a case example of how the Federal Government invests in academic science.[1]

The Federal Government has been instrumental in the computer's rise to strategic importance, starting with the first electronic digital computer, ENIAC, built under Army contract during World War II. The computer might be called an "enabling technology," a tool for advancing research across the spectrum of disciplines. But the Federal agencies' long-term funding of computer science and engineering research, particularly in the universities, has been a primary factor in the emergence and maturation of computer science as a distinctive discipline as well. Today, there is a call for new initiatives in high-performance computing to enhance the Nation's economic and scientific capabilities.[2]

Federal Funding of Computer Research

Between fiscal years 1976 and 1989, Federal obligations for computer science research rose from about $89 million to $487 million. This is equivalent, in 1990 constant dollar terms, to an annual (compound) rate of growth of 8 percent, or a total gain of 170 percent. About 85 percent of this increase occurred after 1980.

Historically, the Department of Defense (DOD) has provided about two-thirds of the Federal funds for computer science research, and accounted for over 60 percent of the increase in total funds since fiscal year 1976.[3] While the National Science Foundation (NSF) is considered the second most important agency in computer science, in funding it has jockeyed for second place with the National Aeronautics and Space Administration (NASA) since the 1980s. Except for its work on the ILLIAC IV supercomputer, NASA's computer science funding was minimal

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[1] See Joel S. Yudken and Barbara Simons, "A Report Summary—Final Report of the Project on Funding Policy in Computer Science," unpublished document, Oct. 15, 1989. Unless otherwise indicated, the data presented below are drawn from the draft report summary, as updated by Joel Yudken, Rutgers University, personal communication, February 1991.

[2] National Research Council, Computer Science and Technology Board, *The National Challenge in Computer Science and Technology* (Washington, DC: 1988), p. 30.

[3] John R.B. Clement, "Computer Science and Engineering Support in the FY 1988 Budget," *AAAS Report XII, Research & Development FY 1988*, AAAS Committee on Science, Engineering and Public Policy, Intersociety Working Group (ed.) (Washington, DC: American Association for the Advancement of Science, 1987), pp. 251-261; and John R.B. Clement and Dianne Edgar, "Computer Science and Engineering Support in the FY 1989 Budget," *AAAS Report XIII, Research & Development FY 1989*, AAAS Committee on Science, Engineering and Public Policy, Intersociety Working Group (ed.) (Washington, DC: American Association for the Advancement of Science, 1988), pp. 260-271.

success. But the metaphor breaks down here because, while success in stock market investments can be gauged by money earned, nothing as tangible results from research—at least not in the short run.[29]

A program "purchases" a portfolio of research projects in a field. The selection of projects for inclusion in this portfolio has been determined by their predicted or estimated quality as seen by contemporary research performers (reviewers) or by knowledgeable research managers (with or without the aid of reviewers). Reviewers usually make judgments about the quality of a project without any direct comparisons of the alternatives facing the investor. Priority setting forces such comparisons. Rather than choosing projects on a one-by-one basis up to the point of resource exhaustion, they could be recommended with reference to their incremental value, i.e., as projects that concentrate or diversify strength in the portfolio. Managers, on the other hand, compare projects with reference to the objectives of the entire program portfolio.

At least for basic research, researchers, reviewers, and program managers are supposed to adjust their activities so quickly that judgments about the quality

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[29] See Harvey Averch, "New Foundations for Science and Technology Policy Analysis," paper presented at the Conference on The Mutual Relevance of Science Studies and Science Policy, May 12, 1989, p. 7.

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until 1982, when its funding jumped up substantially. NSF supports mostly basic research not tied to missions or applications in a full range of computer science and engineering subdisciplines, including theory, software systems and engineering, artifical intelligence and robotics, and advanced computer architecture. The Department of Energy (DOE) involvement in computers dates back to ENIAC in 1945, which was used for calculations for nuclear bomb research at the Los Alamos National Laboratory. DOE (and its predecessor agencies, the Atomic Energy Commission and the Energy Research and Development Administration) has been a major force in the development of high-performance scientific supercomputers ever since.[4]

Federal funding for *academic* computer science research rose dramatically between 1976 and 1989, from over $27 million to $235 million (current dollars), or 320 percent in real terms. DOD, NSF, NASA, and DOE account for virtually all Federal funding of academic research in computer science. (The National Institutes of Health and the National Institute of Standards and Technology both allocate a small number of extramural contracts and grants to universities and colleges.)

DOD has historically been the largest funder of academic computer science and its role increased substantially since 1976. DOD's share of Federal funding for academic computer science rose from 45 percent to 62 percent in fiscal years 1976 to 1989, accounting for over two-thirds of the total increase in this funding during this period. Although NSF funding for academic computer science increased from roughly $14 million to $64 million (current) between fiscal years 1976 and 1989—a real growth of 126 percent—its share of total Federal support for academic computer science declined from 51 percent to 27 percent.

Policy Initiatives in Computer Science Research

Policy initiatives from the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) and the Computer Science and Technology Board of the National Research Council call for substantial funding increases in high-performance computing. The FCCSET proposal has already led to a multiagency request for a $149 million funding augmentation (in what is now called the High Performance Computing and Communications Program), and to new joint Defense Advanced Research Projects Agency-NSF projects.[5] The question of balance and priorities—the shape of the Federal research portfolio for computer science—is likely to persist well into the 1990s.[6]

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[4] Kenneth Flamm, *Targeting the Computer* (Washington, DC: The Brookings Institution, 1987), pp. 78-85.

[5] National Science Foundation, Committee on Physical, Mathematical, and Engineering Sciences, *Grand Challenges: High Performance Computing and Communications* (Washington, DC: February 1991); Executive Office of the President, Office of Science and Technology Policy, ''A Research and Development Strategy for High Performance Computing,'' unpublished document, Nov. 20, 1987; and National Science Foundation, ''Crosswalk of NSF Research Related to the Department of Commerce Emerging Technologies List and the Department of Defense Critical Technologies List,'' in ''Background Material for Long-Range Planning: 1992-1996,'' prepared for a meeting of the National Science Board, June 14-15, 1990, pp. E-1 to E-6.

[6] For a ''call to action'' to computing researchers, see Terry M. Walker, ''Influencing Federal Support for Computing Research,'' *Computing Research News*, vol. 2, July 1990, pp. 1, 10-11.

of any isolated single project remain congruent with developments at the frontiers of knowledge. In practice, the agency investor has no way of knowing whether this ''invisible hand'' is efficient, rapid, and has good discriminating power. So portfolio evaluations could be used to set relative investment priorities since they provide a check on performance at a useful level of budgetary aggregation. But this would require some modification of the criteria for project selection. Reviewers would no longer be ranking proposals by scientific merit alone, but with respect to standards about which they as experts have no special competence, i.e., issues of social merit.

The burden for priorities, then, rests not with those who give advice, but with those who receive and sort it along with other program and agency objectives. To take an example, for the period 1987 to 1991 at NSF, the increase in appropriations for ''research and related activities'' directorates (R&RA) was 39 percent to $1.95 billion (in current dollars). This compares to a 153-percent increase in ''science and engineering education'' to $251 million and a 49-percent increase for the U.S. Antarctic Program to $175 million. Looked at thematically, 80 percent of the requested fiscal year 1991 NSF budget was for research and facilities, and 20 percent for education and human resources (a virtual doubling

Table 5-5—Inhouse Evaluation for the NSF Strategic Plan: Research Advances and Opportunities Lost or Postponed, Research and Related Directorates, Fiscal Years 1987-90

Directorate	Percent change in funding (current dollars)	Research advances	Opportunities lost/postponed
All Research and Related Directorates	39.0%	• Research initiatives to enhance economic competitiveness in biotechnology, global change, manufacturing, materials, supercomputing/networking, superconductivity. • 10 new ERCs, 11 new STCs. • Programs on women/minorities/disabled and undergraduate research and teaching expanded. • Number of proposals up 11.2 percent; number of awards up 4.6 percent.	• Decline of 6.1 percent in proposal success rates and in average annualized award amounts in 5 of 6 directorates (1987-89). • 3 ERCs and 5 materials research labs terminated. • Other STCs deferred.
Biological, Behavioral, and Social Sciences	26.3	• 5 new centers (3 in biotechnology, 1 in plant science—cooperatively with DOE and USDA, and 1 in geography). • Other initiatives in neurobiology, human dimensions in global environment change. • Equipment and instrumentation increases.	• Pursued all proposed, but at reduced levels. • 3-percent decline in proposal success rates.
Computer and Information Science and Engineering	65.5	• NSFNET expansion. • New joint initiative with DARPA in parallel processing. • 4 supercomputer centers renewed. • Infrastructure activities in minority institutions.	• 27-percent decline in success rates. • Fewer grants to groups than planned. • Software engineering initiative delayed. • 1 supercomputer center phased out.
Engineering	39.5	• 7 group research grants for Strategic Manufacturing Initiative. • New initiatives in optical communications, nondestructive evaluation, and management of technology.	• Number of proposals and awards down slightly. • Materials synthesis and processing initiative (with MPS) delayed.
Geosciences	34.8	• Research on Loma Prieta Earthquake. • Initiated active Systems Service.	• Success rates down 3.2 percent. • Canceled some atmospheric science filed programs. • New initiative in mesoscale meteorology deferred.
Mathematical and Physical Sciences	34.1	• Major research equipment subactivity for large research equipment construction projects. • Augmented support for new investigators.	• Success rates down 13.9 percent. • Illinois Macrotron construction canceled. • Material synthesis and processing initiative postponed.
Scientific, Technological, and International Affairs	69.0	• Growth of EPSCoR. • Implementation of Scientific and Technical Personnel Data System. • 6 Minority Research Centers of Excellence initiated.	• Success rate down 9.2 percent. • Undergraduate Education Data System in SRS delayed.

KEY: DARPA=Defense Advanced Research Projects Agency; DOE=U.S. Department of Energy; EPSCoR=Experimental Program to Stimulate Competitive Research; ERC=Engineering Research Centers; MPS=Mathematical and Physical Sciences; NSFNET=National Science Foundation electronic network; SRS=Science Resources Studies; STC=Science and Technology Centers; USDA=U.S. Department of Agriculture.

SOURCE: National Science Foundation, "Background Material for Long-Range Planning: 1992-1996," NSB 90-81, prepared for a meeting of the National Science Board, June 14-15, 1990, pp. C-3 to C-17.

from its share in fiscal year 1987). This reflects the congressionally mandated priority of science education at NSF.[30]

Table 5-5 highlights research advances in its R&RA directorates since 1987, as well as research opportunities seen as lost or postponed. This inhouse evaluation was provided to the National Science Board to assist in its long-term planning. It could also serve as a tool for organization and reorganization (see box 5-F), and as a priority scorecard for the mostly little science that NSF supports.[31]

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[30] These percentages and amounts are based on *requests* in the fiscal year 1991 budget. Still, they approximate how the research directorates have fared relative to other activities at the National Science Foundation. See National Science Foundation, "Background Material for Long-Range Planning: 1992-1996," NSB 90-81, prepared for a meeting of the National Science Board, June 14-15, 1990, p. C-3.

[31] The Antarctic Program is the chief exception, though the National Science Foundation also funds research and development centers such as the National Center for Atmospheric Research, the Kitt Peak and Green Bank telescopes, and five National Supercomputer Centers.

Box 5-F—Behavioral and Social Sciences: Organization and Federal Funding

In the concluding chapter of a National Research Council (NRC) committee report on achievements and opportunities in the behavioral and social sciences, titled "Raising the Scientific Yield," a prescription is offered for ". . . new investments and modifications in research infrastructures that are needed for further progress."[1] The program of prescribed investments total $240 million annually in 1987, a year in which Federal expenditures on behavioral and social sciences research reached the $780 million mark.[2] The research frontiers singled out by the NRC committee for investment include ". . . new inquiries into the connections among behavior, mind, and brain, . . ." ". . . research on the mechanisms of choice and allocation, . . ." ". . . comparative and historical (including prehistorical) study of the institutional and cultural origins of entire societies, . . ." and methodological advances in ". . . data collection, representation, and analysis."[3] But is the level of Federal investment in a broad field of science indicative of its potential contributions?

The behavioral and social sciences tend to get less visibility than other sciences at the Federal agencies, especially the National Science Foundation (NSF) and the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) of the Department of Health and Human Services, which are the primary providers of basic research funding. This dilemma was addressed at a Senate hearing in 1989 by the economist-psychologist and Nobel laureate Herbert Simon.

> It is misleading to talk about "hard" and "soft" sciences. In the physical sciences, classical mechanics is hard, but meteorology (e.g., the greenhouse effect) and the theory of high-temperature superconductivity or low-temperature fusion can be (as recent news stories tell us) exceedingly soft. Similarly, in the social sciences, knowledge about the operation of competitive markets or the capacity of human short-term memory is quite hard; but knowledge about how businessmen and consumers form expectations about the future, or about motivations surrounding drug usage can be quite soft.[4]

To study scientifically what makes us human is as daunting a task as to discover the fundamental forces of the universe or to understand how normal cells become factories of disease.[5] The problem is the priority of funding social research, and opinions may differ on how to institutionalize a Federal commitment to behavioral and social science research.

An Organizational Solution?

In August 1990, Reps. Walgren and Brown introduced H.R. 5543, The Behavioral and Social Science Directorate Act of 1990. This was proposed because, according to Walgren: "NSF's enthusiasm for the behavioral and social sciences is at best lukewarm . . . and the cause is largely structural. Since its creation, this Biological, Behavioral, and Social Science [BBS] Directorate has been headed by a biologist." Brown added that: "NSF as a whole has enjoyed a relatively large increase in funding over the past decade. . . . However, rather than sharing in the Foundation's good fortune, these areas of science have been languishing."[6] The current BBS budget totals $293 million, including $48 million for "behavioral and neural sciences" and $33 million for "social and economic sciences."[7]

While the concept of a separate directorate has been around for at least a decade—the time of Reagan-era cuts—at the 1990 National Behavioral Science Summit, held under the auspices of the American Psychological Society, 65 psychological and behavioral science organizations endorsed the idea as a solution to needed visibility

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[1] Dean R. Gerstein et al. (eds.), *The Behavioral and Social Sciences: Achievements and Opportunities* (Washington, DC: National Academy Press, 1988), p. 239.

[2] Ibid., p. 249.

[3] Ibid., pp. 239-244.

[4] Herbert Simon, testimony, in U.S. Congress, Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space, *National Science and Technology Policy*, Sept. 28-29, 1989, 101st Cong. (Washington, DC: U.S. Government Printing Office, 1989), pp. 264-269.

[5] This was formally recognized when the organic act of the National Science Foundation was amended in 1968, placing within its legal mandate ". . . a formal responsibility to look after the health of basic research in the social and behavioral sciences." See Roberta Balstad Miller, National Science Foundation, "The Contribution of Social Research," John Madge Memorial Lecture, London School of Economics, November 1986, quote from p. 6.

[6] "Behavioral Directorate for NSF Proposed in Congress," *APS Observer*, vol. 3, September 1990, p. 7.

[7] "Social, Behavioral Sciences Seek Upgrade at NSF," *Science & Government Report*, vol. 20, No. 15, Oct. 1, 1990, p. 6.

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Box 5-F—Behavioral and Social Sciences: Organization and Federal Funding—Continued

and bigger budgets.[8] NSF appointed a task force on "Looking to the Twenty-First Century" to study the idea and "... keep several thoughts in mind: 1) BBS must have the flexibility to meet new mandates; 2) BBS must meet the infrastructure needs of its disciplines; and 3) the zero-sum budget situation makes funding reallocations difficult."[9]

In December 1990, the task force voted its intention to recommend establishing a separate NSF directorate for social and behavioral sciences. It would be called Social, Economic, and Psychological Sciences (SEPS).[10] Foremost among the issues the task force must consider are how the boundaries for the behavioral sciences would be drawn, and how interdisciplinary research would be affected. Recommended for inclusion in SEPS are economics, geography, law, linguistics, political science, psychology, and sociology. The interdisciplinary fields of cognitive science and of decision, risk, and management sciences would also be included. Most of neuroscience would stay in the biological directorate. Unresolved are the place of anthropology and some of the programs supporting research on information, robotics, and intelligent systems (now housed in the Computer and Information Science and Engineering Directorate).[11] In lieu of immediately developing a divisional or programmatic structure for SEPS, a new group (including NSF program officers) may be asked to take up the issue.

Whether a separate directorate could aid the management and funding of social and behavioral science research at NSF, and how the agency could assess the effectiveness or productivity of such a new directorate, remains to be seen. Implementation of whatever is finally approved would not occur until fiscal year 1993. It is clear that advocates in the vast majority of behavioral and social science fields (led by psychology) are convinced that "... only by elevating representation of our scientific disciplines will we successfully compete and increase our funding capabilities and our potential contributions to science."[12]

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[8] The question of political vulnerability that accompanies a consolidation of interests in a single structure is the flip side of political gain. For example, concern for the environmental sciences has led to a call for Congress to create a new agency, the National Institutes for the Environment (NIE), modeled on the National Institutes of Health, to stop the erosion of research and training programs related to environmental biology, economics, and policy. Congress has asked the National Academy of Sciences to study the concept of an NIE. See Henry F. Howe and Stephen P. Hubbell, "Progress Report on Proposed National Institutes for the Environment," *BioScience*, vol. 40, No. 8, September 1990, p. 567; and William Booth, "Does Earth Need a Government Institute?" *The Washington Post*, Dec. 10, 1990, p. A13.

[9] "BBS Task Force Meets: Separate Directorate Issue on the Table," *COSSA Washington Update*, Sept. 21, 1990, p. 1.

[10] The final report of the task force is forthcoming. See "NSF Task Force to Recommend New Directorate for Social and Behavioral Sciences," *COSSA Washington Update*, Dec. 7, 1990, pp. 1-2; and "NSF Task Force Discusses Upcoming Report, Agrees to Support SEPS Directorate," *COSSA Washington Update*, Jan. 28, 1991, pp. 1-2.

[11] Anthropology opposes the creation of a new directorate, but the American Anthropological Association has announced that: "Were the proposed reorganization to occur, [anthropology] would elect to be housed . . . " in it. See "Anthropologists Opt for SEPS Directorate," *COSSA Washington Update*, Feb. 10, 1991, p. 2. Applied statistics, ". . . measurement and methodological research, as well as infrastructure issues . . ." are favored by the task force to join the Social, Economic and Psychological Sciences as well. See "NSF Task Force Discusses Upcoming Report," op. cit., footnote 10, pp. 1-2.

[12] Quoted from the American Psychological Association in "NSF Task Force to Recommend New Directorate for Social and Behavioral Sciences," op. cit., footnote 10, p. 1. Also see Alan G. Kraut, "Statement of the American Psychological Society to the National Science Foundation's BBS Task Force on Looking to the 21st Century," unpublished document, Nov. 29, 1990.

The science base, especially at NSF and NIH, carries not only the traditional responsibility for funding scientifically meritorious research, but also for satisfying the expectations that the political system associates with the support of research. These expectations, together with budget constraints, create tougher and tougher choices. The agencies cope admirably with this complex task. In the next section, OTA examines another category of research funding: science megaprojects.

Science Megaprojects

The Federal Government has a long history of supporting projects such as the building and operation of dams, bridges, and transportation systems. These projects are large-scale, complex, costly, and long-term undertakings. In addition to performing their primary function, these programs also provide jobs and local public works, and have long-term economic value. Thus, they are often called "megaprojects."

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As the body of scientific knowledge grows more sophisticated and costly, research instrumentation and infrastructure are required in some fields.[32] As projects expand, they become valuable economically and politically. For example, the Hubble Space Telescope, launched in April 1990, cost over $2 billion, although the original estimate was as low as $300 million.

> By the time the real costs were known, it was too far along to stop. As a practical matter, Congress refused to write off as wasted the hundreds of millions it already had sunk into the project. Politically, the device had taken on a pork-barrel life of its own, sending government money to nearly half the 50 States and employing thousands.[33]

Although economic activity may be a second- or third-order consideration among the initial criteria of project selection, the distribution of Federal monies, as an interim payoff on a long-term investment, can be substantial. For instance, the three megaprojects shown in figure 5-3, the Hubble Space Telescope, the Space Station, and the SSC, enjoy widespread economic and social merits, regardless of their scientific merit.

Among the megaprojects recently listed by *The Chronicle of Higher Education* are the SSC, the Space Station, the Moon-Mars mission, the hypersonic aircraft, the Earth Observing System, the Strategic Defense Initiative, and the Human Genome Project (HGP). The original estimates for these seven projects alone totaled $528 billion. A September 1990 cost estimate for the same projects was about $580 billion,[34] or $65 billion annually.[35]

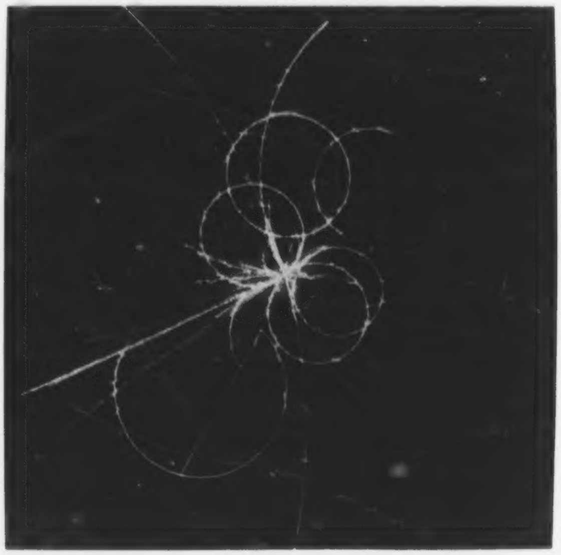

Photo credit: U.S. Department of Energy

Each of these lines is a trace of the path of a subatomic particle. This picture is an example of the kind of data that can only be produced by the Superconducting Super Collider (SSC). The SSC is expected to produce traces of particles never seen before.

What Constitutes a Science Megaproject?

Megaprojects are large, lumpy, and uncertain in outcomes and cost. "Lumpy" refers to the discrete nature of a project. Unlike little science projects, there can be no information output from a megaproject until some large-scale investment has occurred.[36] OTA also would define a science megaproject as requiring very large expenditures (especially when

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[32] One philosopher argues that the further and further we get from direct sense experience, the more costly and complex research technologies we need for progress. See Nicholas Rescher, *Scientific Progress: A Philosophical Essay on the Economics of Research in Natural Science* (Pittsburgh, PA: University of Pittsburgh Press, 1978). The section below is based on Averch, op. cit., footnote 28.

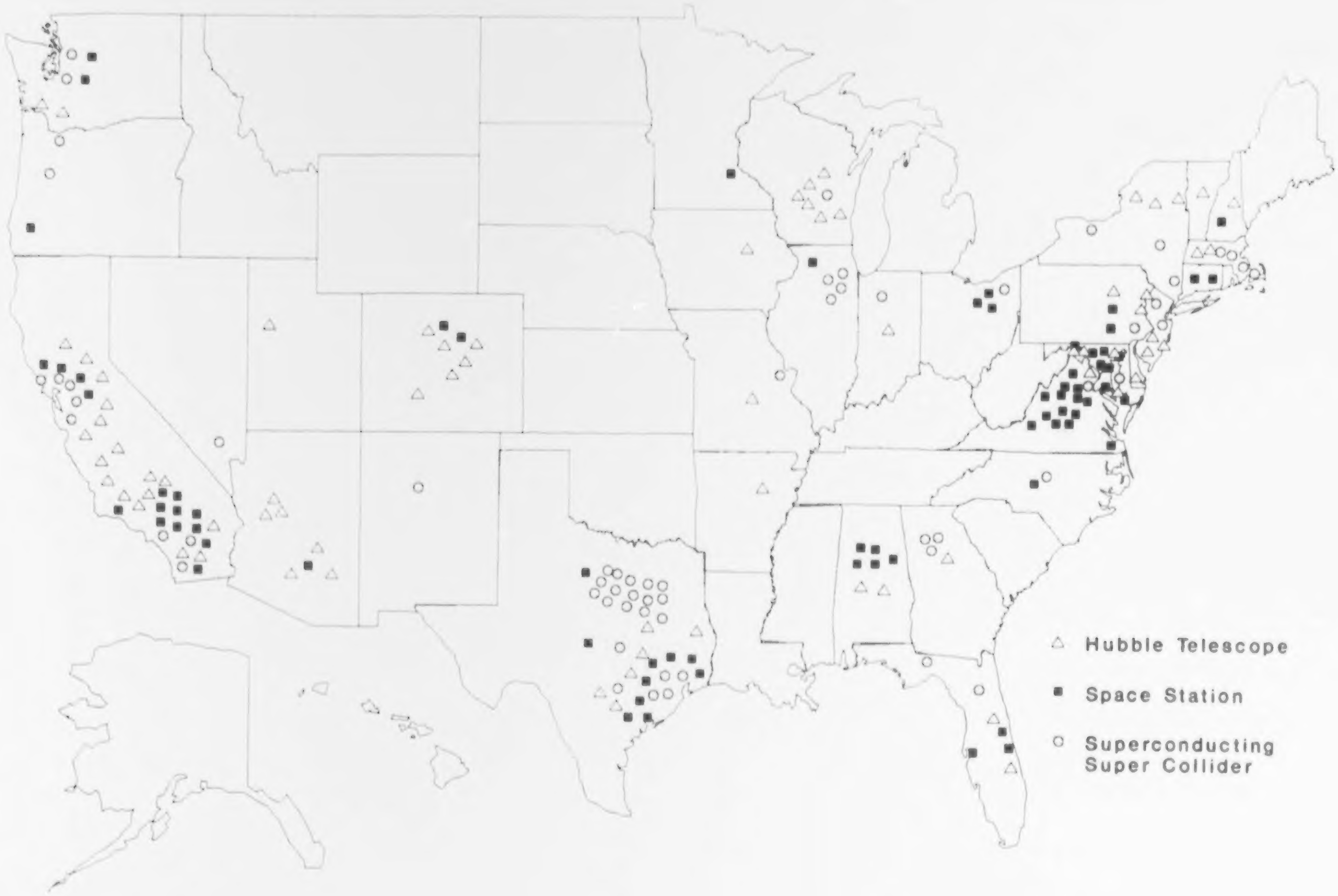
[33] Phil Kuntz, "Pie in the Sky: Big Science Is Ready for Blastoff," *Congressional Quarterly*, vol. 48, Apr. 28, 1990, p. 1254. Also see Kim A. McDonald, "Researchers Increasingly Worried About the Unreliability of Big Science Projects," *The Chronicle of Higher Education*, vol. 36, No. 48, Aug. 15, 1990, pp. A1, A8-A9.

[34] Colleen Cordes, "Big Science and Technology Projects Near Important Milestones in Face of Federal Budget Crunch and Mounting Criticism," *The Chronicle of Higher Education*, vol. 37, No. 2, Sept. 12, 1990, p. A28, reports original and current cost estimates submitted to Congress just for the R&D investments required for the seven projects (most not adjusted for inflation). High-technology R&D project cost *estimates* are notoriously (but unsurprisingly) low. For example, a number of RAND Corp. studies show the underestimation in the actual costs to develop high-tech military aircraft. See P.W.G. Morris and G.H. Hough, *The Anatomy of Major Projects: A Study of the Reality of Project Management* (New York, NY: John Wiley & Sons, 1987).

[35] See "Big Science: Is It Worth the Price?" *The New York Times*, May 27, 1990, p. 11, and June 5, 1990, p. C1.

[36] It is not possible to build one-half of a dam, one-half of a ship, or one-half of an airplane and get the desired performance. These technologies are, of course, well enough in hand that one can estimate or predict the results from investing in them. There is a very extensive literature on appraisal and management of capital projects such as dams, airports, ports, and also a sizable literature on estimating the worth of private sector capital investments in factories and equipment. Among the literature on managing large complex technological systems, literally nothing is written on selecting them. But see Harvey Sapolsky, *The Polaris System Development: Bureaucratic Success in Government* (Cambridge, MA: Harvard University Press, 1972).

Figure 5-3—Where the Money Goes for Three Megaprojects


△ Hubble Telescope
■ Space Station
○ Superconducting Super Collider

SOURCE: Map by Sharon Perkinson in Phil Kuntz, "'Pie in the Sky: Big Science Is Ready for Blastoff," *Congressional Quarterly Weekly Report*, vol. 48, Apr. 28, 1990, p. 1255.

compared with other investments in the same or similar fields) to create knowledge that is unattainable by any other means.

Perhaps equally important in the definition of science megaprojects, however, are the political components. Each project is unique in its development, especially in its progress through the budget processes at the research agencies. Also, science megaprojects are supported by large political constituencies extending beyond the scientific community. In short, there are few rules for selecting and funding science megaprojects; the process is largely ad hoc. To illustrate, OTA presents two widely acknowledged examples of big science projects—the SSC and the HGP.

The Superconducting Super Collider

The SSC, when built, will accelerate two counter-circulating beams of protons at energy level 20 TeV to "create" rarely seen elementary particles when these beams collide. Expected to cost at least $8 billion to construct, the SSC represents one of the world's largest scientific instruments.[37] Amidst contentious debate in Congress, the SSC won funding approval to begin construction in June 1989. DOE decided to build the 54-mile-in-circumference accelerator south of Dallas, Texas; it is expected to begin operation in 1999.[38] Director Emeritus of Fermi National Accelerator Laboratory, Leon Lederman, has said in House testimony that ". . . instead of trying to kill off a big target like the SSC . . . the collider should be seen as the 'flagship' for big increases for science [funding]."[39]

The SSC clearly meets the specific criteria outlined by OTA for a big science project (high cost and unique outcomes). It also satisfies the political criteria. First, the SSC has important scientific goals that can be obtained in no other way. Second, the high-energy physics community has marshalled support of the SSC from DOE, which administers the project, and the State of Texas, where it will be built. Finally, the SSC originated in DOE discussions with the high-energy physics community, and was preferred by the Department's High Energy Physics Advisory Panel to the equivalent amount invested in smaller, less costly high-energy physics.[40] As with many big science projects, however, it is also true that, without the prospect for such an accelerator, the equivalent amount would most likely *not* be available to physicists—or indeed to scientists in other fields—at all.

The Human Genome Project

The HGP, estimated to cost $3 billion to complete, is expected to yield a high-quality genetic map of the human genome. The HGP is "big" biology in lifetime costs and mode of organization (e.g., scientists clustered in "mapping" centers) relative to the rest of biomedicine.[41] An annual $200 million appropriation would represent 5 percent of NIH's funding for untargeted research.[42] Its fiscal year 1991 appropriation is $135 million. HGP organizers stress that funding for the project since its inception has been "new" money. Funds from other budget categories at NIH have not shifted to the HGP, i.e., none have decreased since the inception of the project.[43]

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[37] See David P. Hamilton, "The SSC Takes On a Life of Its Own," *Science*, vol. 249, Aug. 17, 1990, pp. 731-732; and Marcia Barinaga, "The SSC Gets Its (Official) Price Tag: $8.3 Billion," *Science*, vol. 251, Feb. 15, 1991, pp. 741-742.

[38] See U.S. Department of Energy, Office of the Inspector General, *Special Report on the Department of Energy's Superconducting Super Collider Program*, DOE/IG-0291 (Germantown, MD: Nov. 16, 1990).

[39] Quoted in Colleen Cordes, "Calls for Setting Science-Spending Priorities Are Renewed as Supercollider Gets Go-Ahead, NSF Faces Pinch," *The Chronicle of Higher Education*, vol. 35, No. 46, July 26, 1989, p. A23. Notice the tradeoff language in the headline.

[40] In spring 1990, the Department of Energy's High Energy Physics Advisory Panel ranked research goals for the 1990s: building the Superconducting Super Collider (SSC) was first, upgrading Fermilab's proton-proton Tevatron collider was second, and supporting university-based investigators received honorable mention. See "Physics Panel Sets Priorities for 1990s," *Science*, vol. 248, May 11, 1990, p. 681. This also emerged from OTA staff interviews at the Department of Energy, spring 1990. In a January 1991 news release, the Council of the American Physical Society, for the first time in its 93-year history, ". . . overwhelmingly adopted a public position on funding priorities. Top priority is given to support of individual investigators and 'broadly based physics research.' " The statement also endorses construction of the SSC in a ". . . timely fashion, but the funding required to achieve this goal must not be at the expense of the broadly based scientific research program of the United States." See American Physical Society, "First APS Council Statement on Funding Priorities," news release, Jan. 28, 1991.

[41] Tom Shoop, "Biology's Moon Shot," *Government Executive*, February 1991, pp. 10-11, 13, 16-17.

[42] In fiscal year 1990, the Human Genome Project is budgeted for $90 million at the National Institutes of Health (NIH) and $46 million at the Department of Energy. The NIH amount represents 1 percent of its total budget. See Leslie Roberts, "A Meeting of the Minds on the Genome Project?" *Science*, vol. 250, Nov. 9, 1990, pp. 756-757.

[43] Stu Borman, "Human Genome Project Moving on Many Fronts," *Chemical & Engineering News*, vol. 68, No. 50, Dec. 10, 1990, pp. 6-7.

Critics of the HGP contend that it flaunts tradition in the administration and performance of biomedical research. They are also "... not convinced that a crash program for analyzing the structure of genomes will advance either health or the life sciences for many years to come."[44] Proponents of the project stress its development of automated technologies for molecular biology, including mapping and sequencing, and of new computational approaches that apply computer science to biology. Thus, "... a new type of interdisciplinary biologist who understands technology as well as biology ..." is being trained. Besides, in the words of molecular biologist Leroy Hood:

> The HGP primarily funds single investigator-sponsored research. It is not big science. Rather, by making the human chromosomal map and sequence available to small laboratories, it allows them to compete with large laboratories. Hence, the HGP is the guarantor of small science.[45]

The HGP was originally billed as a project that would contribute to the cures for all disease.[46] As legislators skeptically claimed that they had heard this "promise" from life science projects before, proponents of the project began to promote the HGP on its other potential strengths, including contributions to economic competitiveness. For instance, Hood stated that HGP "... will in turn spawn new industrial opportunities. ... The HGP will prime the American economic pump."[47]

At issue in the designation of this science project as "big" is more than cost and organization, but the timing of the research investment and its impact on both the culture and justification for biomedical research. The 1 percent of NIH's budget is a small investment, but it represents the reordering of criteria and the disruption of research-as-usual.

The Process of Megaproject Selection

From a national perspective, megaprojects are very large projects that stand alone in the Federal budget and cannot be subject to priority setting within a single agency. Nor can megaprojects be readily compared. The SSC and HGP are not big science in the same sense. One involves construction of a large instrument, while the other is a collection of small projects. There also exists virtually no scholarly literature to guide the selection of megaprojects designed to promote the state of the art of scientific fields.[48] At issue with many megaprojects is their contribution to science. For instance, the Space Station has little justification on scientific grounds,[49] especially when compared with the SSC or the Earth Observing System, which have explicit scientific rationales. At present, the Space Station does have considerable momentum as an economic and social project.[50] However, many question the uniqueness of these benefits because other projects, such as the Earth Observing System, could certainly provide many jobs as well. Because the problem of selecting among science megaprojects has most in common with the selection of complex capital projects, timeliness (why do it now rather than later?) and scientific and social merit must all be considered.

The tradeoffs among these criteria are complex, even when restricted to considerations solely within

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[44] Bernard D. Davis, "Human Genome Project: Is 'Big Science' Bad for Biology?—Yes: It Bureaucratizes, Politicizes Research," *The Scientist*, vol. 4, No. 22, Nov. 12, 1990, p. 15.

[45] Leroy E. Hood, "Human Genome Project: Is 'Big Science' Bad for Biology?—No: And Anyway, the HGP Isn't 'Big Science,' " *The Scientist*, vol. 4, No. 22, Nov. 12, 1990, p. 15. For an elaboration, see Walter Gilbert, "Towards A Paradigm Shift in Biology," *Nature*, vol. 349, Jan. 10, 1991, p. 99.

[46] See U.S. Congress, Office of Technology Assessment, *Mapping Our Genes: Genome Projects—How Big, How Fast?* OTA-BA-373 (Washington, DC: U.S. Government Printing Office, April 1988).

[47] Hood, op. cit., footnote 45, p. 13.

[48] The journal *Technology in Society* devoted one full issue in 1988 and another in 1990 to the political and social consequences of large technological projects, but no author discussed algorithms for selecting them. Also see William C. Boesman, "Historical Perspective on Large U.S. Science Facilities," *CRS Review*, February 1988, pp. 8-10; and Peter Monaghan, "Historians Seek More Detailed Study of Big Science Projects to Inform Debate Among Researchers and Policy Makers," *The Chronicle of Higher Education*, vol. 37, No. 14, Dec. 5, 1990, pp. A5, A8.

[49] For an early statement of this view, see U.S. Congress, Office of Technology Assessment, *Civilian Space Stations and the U.S. Future in Space* (Springfield, VA: National Technical Information Service, November 1984).

[50] This momentum may be slowed by the latest statement of "no confidence" in the scientific content of Space Station Freedom in a forthcoming National Academy of Sciences report. See David P. Hamilton, "Space Station Shrinkage To Affect Scientific Mission," *Science*, vol. 251, Mar. 8, 1991, p. 1167; and Eliot Marshall, "Two Thumbs Down for Space Station," *Science*, vol. 251, Mar. 22, 1991, p. 1421.

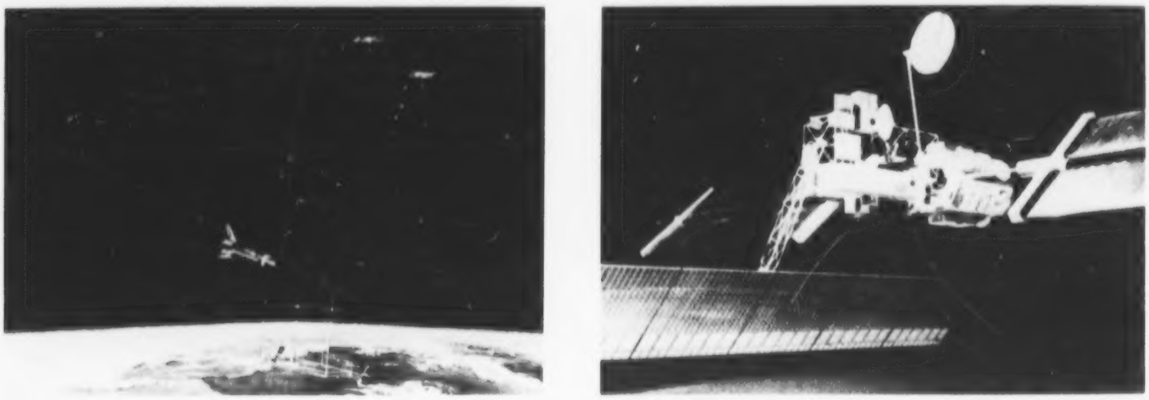

Photo credit: National Aeronautics and Space Administration

In the early stages of megaproject development, it is often difficult to obtain firm estimates of cost because plans can change radically. In 1982, the Earth Observing System (EOS) was conceived as a large space antenna system, as in the artist's rendering on the left. By 1990, the conception of EOS had changed to include "platforms" in space and other features, as shown on the right.

the scientific community. One observer puts the dilemma of weighing social and scientific merit this way:

> Scientific progress depends heavily on scientific capital; scientific capital is built up by investments in training, equipment, pilot research, and the accumulation of expertise over extended periods. A single very large project may have great scientific and social benefits, but if it can be done only by shutting down existing lines of research in other areas, the opportunity losses—the loss of the benefits these lines of research would have produced, plus the cost of duplicating in the future the capital investments in them—can outweigh the gains from the larger project. It is very difficult to estimate the losses from opportunities foregone; however, we do know that a small proportion of studies trigger the kind of dramatic breakthroughs that transform life in ways the original researchers themselves rarely envision.[51]

In addition, funds are still obligated to agencies. So assurances notwithstanding, the research community perceives megaprojects as new money for an initiative that could supplant older, S&T base programs, and would be added to agency budgets if the megaproject did not exist.[52]

On a national scale, criteria and tradeoffs are even more difficult to quantify, since completely separate fields are represented. The social and scientific benefits that will derive from investing in one are incommensurable with those that would be derived from investing in some other.[53] So weighing the scientific, technological, and development benefits that will result from the projects will not suffice; economic and labor benefits must also be considered. Other criteria might also include education and training benefits, and the impact of the project on the research community measured in per-investigator costs. For instance, if one project will benefit only a few researchers, while a second of similar cost will benefit a larger number of researchers, then perhaps the second should be favored.

One might also expect preference for megaprojects that can be cost-shared internationally over those that cannot be. This conceives of megaproject output as a contribution to world science, i.e., as

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[51] Robert L. Stout, "Evaluating Scientific Initiatives," letter, *American Scientist*, vol. 77, No. 3, May-June 1990, pp. 211-212. The opportunities presented by megaprojects should be compared with the foregone benefit of little science at the margin, not on average.

[52] This has been charged repeatedly about AIDS funding relative to the rest of the National Institutes of Health budget. For example, see David T. Denhardt, "Too Much for AIDS Research," *The Washington Post*, Oct. 2, 1990, p. A19.

[53] See, for example, J. E. Sigel et al., "Allocating Resources Among AIDS Research Strategies," *Policy Sciences*, vol. 23, No. 1, February 1990, pp. 1-23. The authors asked 17 nationally known AIDS experts to estimate the marginal or incremental value of additional funds for different AIDS research investments in terms of some prespecified social outcomes. The information that would be gained from these different investments is incommensurable, but their expected contribution to the pre-specified social outcome allows them to be ordered. The megaproject problem, however, is more like judging research investments in AIDS v. heart disease v. cancer.

Table 5-6—A Comparison of Science Megaprojects (in billions of dollars)

Project	Original cost estimate	Most recent estimate	Spent so far (since)	Timeframe (years)
Hubble Telescope	$0.29-0.34 (1973)	—[a]	$2 (1978)	—[a]
Space Station	8 (1983)	$37	4 (1985)	16
Superconducting Super Collider	4.4 (1987)	8.6	0.35-0.43 (1988)	11
Human Genome	3 (1988)	3	0.16 (1988)	15

[a] Project completed

NOTE: Original cost estimates do not include inflation, while the recent estimates and the amount spent so far include inflation. Hubble expenditures include development ($1.5 billion) and operating costs ($0.5 billion), from fiscal years 1978-1991. All cost estimates are rounded.

SOURCES: Based on "The Outlook in Congress for 7 Major Big Science Projects," *The Chronicle of Higher Education*, vol. 37, No. 2, Sept. 12, 1990, p. A28; Genevieve J. Knezo, "Science Megaprojects: Status and Funding, February 1991," *CRS Report for Congress*, 91-258 SPR (Washington, DC: Congressional Research Service, Mar. 12, 1991); Phil Kuntz, "Pie in the Sky: Big Science Is Ready for Blastoff," *Congressional Quarterly Weekly Report*, vol. 48, Apr. 28, 1990, pp. 1254-1260; and National Aeronautics and Space Administration, Office of Resources Analysis, Office of the Comptroller, personal communication, March 1991.

information appropriable by all who want it and can benefit. The SSC would not be defined as a competitor of CERN (the European Organization for Nuclear Research in Geneva, Switzerland) in some private particle race pursued by U.S. high-energy physicists; there would also be no national objective to keep the American rate of discovery above that of European or Japanese physicists.[54] While the prevailing claim is that "priority races" are necessary to make progress in science, cost- and information-sharing are consistent with a view of research as an appropriable, world public good.[55]

While scientific and social merit are abstract, they provide a framework to evaluate the merits of proposed big science projects. More concrete concerns include the range of megaproject costs and their management.

Megaproject Costs and Management

The Federal Government buys big science initiatives, and the initial investment may represent a point of no return. Once the "go, no-go" decision has been made at the national level, the commitment is expected to be honored, no matter how much the cost estimates or timetables for completion change. However, criteria for consideration in the funding of a science megaproject could conceivably include: startup and operating costs, and likely changes in the overall cost of the project from initial estimate to completion. Table 5-6 presents a comparison of four projects, which shows that the cost estimates for some big science projects double before they are even begun.

Table 5-7 presents the budget authority for four projects in fiscal years 1990 and 1991. The percentage increases requested are considerably larger than the average annual increase in total budgets proposed for the cognizant research agencies. The costs incurred in future years by most megaprojects are enormous, and it is unclear that all of the projects currently receiving funds can be supported in coming years.

In addition, costs for maintenance of a big science facility once it is operational are rarely considered.

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[54] See S.S. Yamamoto, "A Genuine Global Partnership?" *Nature*, vol. 346, Aug. 23, 1990, p. 692. This has likewise been an issue in the Human Genome Project, since James Watson, Director of the National Institutes of Health's National Center for Human Genome Research, has been outspoken about the disappointing level of funding and commitment to the project by the governments of Japan and France. See Borman, op. cit., footnote 43, p. 7. Also, the benefits of megaprojects include not only the scientific knowledge generated, but the technological know-how gained in designing and building the instruments.

[55] Two literatures are relevant here. One is on analysis of "simultaneous multiple discoveries" and creativity in science; the other is on data sharing and the diffusion of knowledge. On the former, see Dean Keith Simonton, *Scientific Genius: A Psychology of Science* (Cambridge, England: Cambridge University Press, 1988); on the latter, see David S. Cordray et al., "Sharing Research Data: With Whom, When, and How Much?" paper presented at the Public Health Service Workshop on Data Management in Biomedical Research, Chevy Chase, MD, Apr. 25-26, 1990; and Eliot Marshall, "Data Sharing: A Declining Ethic?" *Science*, vol. 248, May 25, 1990, pp. 952, 954-955, 957.

Table 5-7—Four "Big Science" Initiatives in the Fiscal Year 1991 Budget (estimates in millions of current dollars)

Initiative	Fiscal year 1990 enacted	Fiscal year 1991 proposed	Proposed percent increase	Fiscal year 1991 enacted	Enacted percent change
Strategic Defense Initiative	$3,600	$4,500	25%	$2,900	-19%
Space Station	1,750	2,451	40%	1,900	9%
Superconducting Super Collider	225	331	47%	243	8%
Human Genome	60	108	41%	88	47%
Total	5,635	7,390	31%	5,131	-9%

SOURCE: Michael E. Davey, Congressional Research Service, "Research and Development Funding: FY1991," issue brief IB90048, Nov. 13, 1990.

The Space Station promises to require at least $1.5 billion per year in maintenance—an amount not figured into original cost estimates.[56] Much of the maintenance support will be transported by the Shuttle, which has proven less than reliable in recent years. These concerns raise questions about how realistically operations are weighed in securing approval of megaprojects.

Another concern is the ''top-down'' organization of big science projects. For example, one critic of the HGP endorses both the goals and the quality of the science so far, but calls it ''. . . overtargeted, overbudgeted, overprioritized, overadministered, and . . . micromanaged.''[57] In contrast, some projects are criticized for a lack of management: ''Though over $4 billion has been spent so far on the Space Station, it exists only as a paper design, and with virtually no purpose beyond serving as a platform for the glamour of man in space.''[58] Clearly, management is an important consideration in megaproject development.

Any big science project on the forefront of expertise will involve considerable learning by doing. Once a megaproject has been selected, real-time evaluations of its progress can also be carried out that give rapid feedback to those involved.[59] While there is no guarantee that agency sponsors of megaprojects will listen to evaluators, the latter can become another constituency defined into the decisionmaking process.

In sum, megaprojects will always be selected through a political, public process because of their scale, lumpiness, and incommensurability. Yet, for each initiative, as the NAS priority report reminds: ''. . . it is necessary to specify the institutions, individuals, and organizations that will be served; the costs; the opportunities for international cooperation and cost sharing; the management structure; and the timeliness of the program.''[60] The cost of investment for the Federal Government and the cost per investigator are criteria that apply to all science initiatives. The designations ''big'' and ''little'' are quite variable when projected over time and relative to the total value of an agency's portfolio. Clearly, the process of making Federal research investments could become more iterative, less sequential, and better oriented to national goals. OTA next examines an alternative to current practice.

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[56] Cordes, op. cit., footnote 34, p. A28.

[57] Don Brown quoted in Roberts, op. cit., footnote 42, p. 756. For example, there are now a total of six National Institutes of Health-supported genome research centers and growing questions about acceptable costs and error rates in sequencing a genome before deposit in a database. See ''New Human Genome Centers Established,'' *Chemical & Engineering News*, vol. 69, No. 6, Feb. 11, 1991, p. 16; and Leslie Roberts, ''Large-Scale Sequencing Trials Begin,'' *Science*, vol. 250, Dec. 7, 1990, pp. 1336-1338.

[58] ''Man-in-Space: The Self-Inflicted Curse of NASA,'' *Science & Government Report*, vol. 20, No. 13, Aug. 1, 1990, p. 4.

[59] See K. Guy and L. Georghiou, ''Real-Time Evaluation and the Management of Mission-Oriented Research: The Evaluation of the Alvey Program—Aims, Achievements and Lessons,'' unpublished paper, presented at the ECE Seminar on Evaluation in the Management of R and D, Apr. 3-7, 1989. In addition, if real-time evaluation had been heeded in the construction of the Hubble Telescope, for instance, a full-scale test of the mirror could have been performed. See Bob Davis, ''NASA Management Flaws Led Agency to Overlook Hubble Defect, Panel Finds,'' *Wall Street Journal*, Nov. 27, 1990; and William Booth, ''Hubble Report Faults Builder, NASA,'' *The Washington Post*, Nov. 28, 1990, p. A8.

[60] National Academy of Sciences, op. cit., footnote 17, p. 11.

Research Priorities and the "Big Picture"

Figure 5-4 depicts the projected outlays for the science base and science megaprojects discussed above. The projected expenditures for big science projects rise in the 1990s as an increasingly significant portion of those for science projects as a whole. (Since cost estimates for megaprojects tend to grow precipitously, a similar figure that doubles those expenditures are included for sake of comparison in figure 5-4.[61]) Within the current funding climate and that predicted for the 1990s, perhaps not all components of the current Federal research portfolio can be supported. Choices among science projects may need to be made. Because of the large projected lifetime costs associated with each megaproject, sorting and recalibrating the costs of each earlier rather than later would be useful.

How could such choices be made? Ideally, one might ask that Federal funds be allocated to the science base and then add megaprojects in order of importance until funds are depleted. However, such a sequential approach is not realistic. First, there is nothing that corresponds to a single research budget. Many countries, for example, Canada, Germany, and Sweden, have capital budgets for all functions, including research. If the United States had a capital budget distinct from its operating budget, then it could rate megaprojects against one another and compare them with other capital investments. Second, megaprojects are funded on an equal footing in many agencies with other research programs. Finally, in the words of Albert Teich, of the American Association for the Advancement of Science:

> Advocates of systematic priority setting and those who may be called on to advise in the process need to recognize that any such rational analysis is just one element of the picture. Such analysis may influence the process, but it does not determine priorities. Other factors and other voices will and should be heard. Political criteria are not a contaminant in the allocation of public resources for research; they are absolutely essential to the democratic process and to the long-run effective functioning of the system.[62]

An annual review of commitments across categories of investment would help to gauge balance by field, research problem, and agency contributions to the achievement of national goals. By revisiting these categories year after year, Federal investments could be appraised to add and subtract from the Nation's research portfolio.[63]

Once the context for priority setting is examined, tradeoffs and choices take on another dimension. What do U.S. society and the Federal Government expect for their research investment? What does the scientific community promise to deliver? The answers differ among participants and over time. The answers differ because criteria and expectations differ, because there are plural research systems, and because participants can influence the process of budgeting and research decisionmaking at many levels.

Although scientific merit and program relevance must always be the first criteria used to judge a research program or project's potential worth, they cannot be the *sole* criteria. First, in today's research system, there are many more scientifically meritorious projects than can be funded. In its initial effort to document stress on the Federal research system created by an abundance of research applications, OTA found that an increasing proportion could not be funded by various research agencies due to budget limitations, rather than to deficiencies of quality.[64] Second, rewarding scientific merit and relevance alone can inhibit the system from preparing for the future. This problem is seen clearly in the funding of young investigators. Since the prospective yield of new knowledge is judged by the technical merit (e.g., soundness of design or experimental protocol) of a project proposal, its scientific creativity, *and* the track record of the scientist, young investigators are at a disadvantage, and other criteria must be weighed when evaluating their proposals.

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[61] Note that some estimates of megaprojects include only capital costs, while other include capital and operating costs.

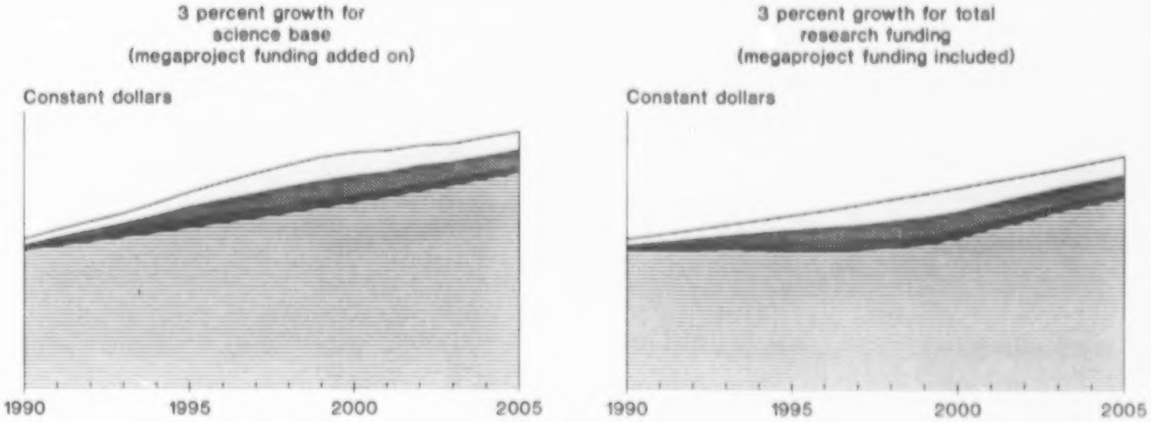
[62] Albert H. Teich, "Scientists and Public Officials Must Pursue Collaboration To Set Research Priorities," *The Scientist*, vol. 4, No. 3, Feb. 5, 1990, p. 17.

[63] To iterate is to plan and exercise flexibility within a budget envelope—much like a National Basketball Association team shuffling its roster to stay under the league's imposed salary cap while enjoying a full complement of players at every position.

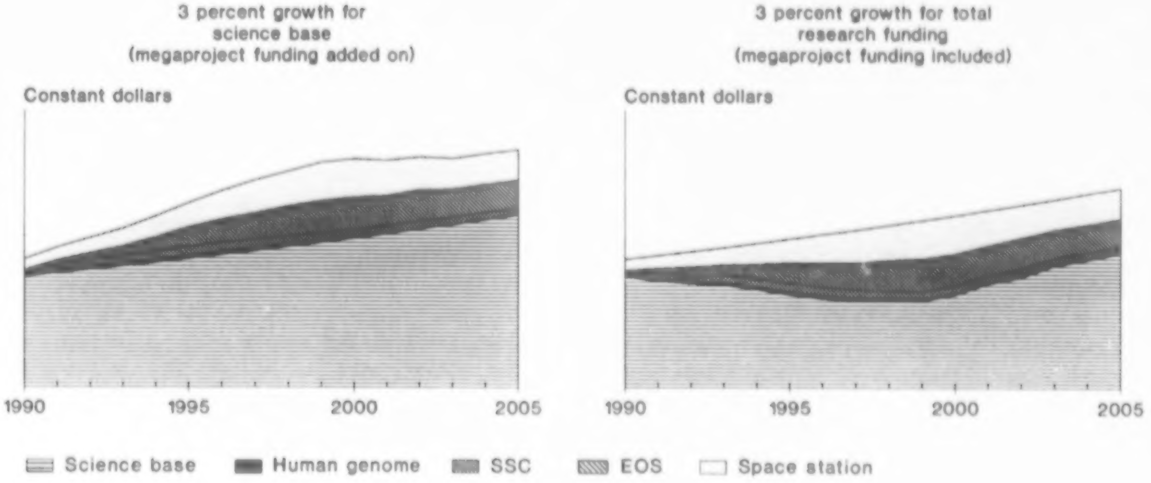
[64] U.S. Congress, Office of Technology Assessment, "Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System," staff paper of the Science, Education, and Transportation Program, April 1990.

Figure 5-4—Cost Scenarios for the Science Base and Select Megaprojects: Fiscal Years 1990-2005

Current cost estimates for megaprojects



Doubled current cost estimates for megaprojects



KEY: SSC=Superconducting Super Collider; EOS=Earth Observing System.

NOTE: These figures are schematic representations of projected costs for science projects. In the figures on the left, the *science base* is projected to grow at an annual rate of 3 percent above inflation. In the figures on the right, *total research funding* is projected to grow 3 percent above inflation. The cost estimates for the megaprojects are based on data from "'The Outlook in Congress for 7 Major Big Science Projects," *The Chronicle of Higher Education*, vol. 37, No. 2, Sept. 12, 1990, p. A28; and Genevieve J. Knezo, "'Science Megaprojects: Status and Funding, February 1991," *CRS Report for Congress*, 91-258 SPR (Washington, DC: Congressional Research Service, Mar. 12, 1991).

SOURCE: Office of Technology Assessment, 1991.

There is a role for Congress to set priorities across and within categories of science and engineering research. The application of criteria that augment "scientific merit" and "program relevance"—which are *today's* judgments of quality—would clarify *tomorrow's* objectives of research investment. As discussed in chapter 1, broadly stated, there are two such criteria: strengthening education and human resources (i.e., increasing the number and diversity of participants); and building regional and institutional capacity (including economic development by leveraging Federal research support).[65] Both sets address the future capability of the research system in response to national needs, and both can be employed in mainstream and set-aside programs.

Conclusions

Since progress begets more opportunities for research than can be supported, setting research priorities may be imperative for the success of science in the 1990s.[66] And while the questions raised in this chapter have a familiar ring—how should Federal monies for research be spent? which opportunities for scientific advance merit funding now? who should decide?—the search for a framework to judge criteria of choice has grown urgent. In the pluralistic and decentralized system of research decisionmaking, sponsorship, and performance, there are ample voices to justify most any hierarchy of programs and projects on the grounds of "social" or "scientific" merit. The question of what do U.S. society and the Federal Government want for their research investments has many answers.

Long before the onset of stringency in Federal discretionary funding, priority setting was an integral part of the regular budget process:

> By the time any budget for science has been pulled apart by function in the budget committees, by agency in the legislative committees, and by appropriations bills in the appropriations committees (in both House and Senate at each of these levels) and reassembled among the various other programs of veterans' benefits, sewage treatment grants, and agricultural price supports, its internal priorities will be unrecognizable.[67]

The problem is not a lack of priority setting. The problem is implementing priorities in the name of national goals and scientific needs. How can that be achieved?

Some observers of the current priority-setting process have suggested improvements to the process that are structural, in particular centralizing the budget process and intensifying research planning within and across the agencies. This would make the tradeoffs more explicit and less ad hoc, and the process more transparent. At a minimum, multiyear budgeting and an agency crosscutting budgetary analysis (proponents like NAS say) could reduce uncertainty in budgeting.[68]

To ensure that priorities are set, some persons, committees, or bodies of the Federal Government, in addition to the President, must be invested with the power to set priorities. Agency managers are already performing this function at a program level, with oversight from the legislative branch. At the highest level of decisionmaking, however, a crosscutting function is required. In the executive branch, OSTP and OMB are the only actors with the ability to play such a sweeping role. Without additional legislative initiatives, however, OSTP is hampered by the powerlessness of its advisory position. And OMB, which has been serving a crosscutting function in the executive branch, is not receptive to incorporating debate and public decisionmaking on these issues. Congress already serves, in part, a crosscutting priority-setting function. However, Congress has traditionally been reticent to set priorities. Suggestions have been made to strengthen Congress' hand in research decisionmaking through structural change in the budget process, and there has been an evolution toward greater congressional activism. However, Congress may wish to strengthen its current role as the final arbiter of priorities and invest others with the discretion to propose priorities.

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[65] Some agency programs already incorporate these criteria. They are explicitly in use, for example, at the National Science Foundation (NSF) (though not in every program or directorate) and there have been no claims that scientific merit has been compromised. At other agencies, however, these criteria are seen as not as important to the research mission (OTA interviews, spring 1990). At the same time, set-aside programs at NSF and elsewhere underscore the continuing need for "sheltered competitions" for researchers who do not fare well in mainstream disciplinary programs.

[66] Brooks writes: "Today many of the same negative signals that existed in 1971 are again evident. Will science recover to experience a new era of prosperity as it did beginning in the late seventies, or has the day of reckoning that so many predicted finally arrived?" Harvey Brooks, "Can Science Survive in the Modern Age? A Revisit After Twenty Years," *National Forum*, vol. 71, No. 4, fall 1990, p. 33.

[67] Teich, op. cit., footnote 62, p. 18.

[68] This was, of course, prior to the 1990 budget summit and passage of the Deficit Control Act discussed in ch. 3. The National Academy of Sciences discussion is nevertheless instructive. See National Academy of Sciences, op. cit., footnote 17, pp. 11-16, especially table 2. Also see U.S. General Accounting Office, *U.S. Science and Engineering Base: A Synthesis of Concerns About Budget and Policy Development*, GAO/RCED-87-65 (Washington, DC: March 1987), especially pp. 22-56.

Whatever Federal body is designated as having the authority of initial choice, its task should extend at a minimum to the iterative planning and appraisal of accounts that results in: a) limiting the number of (or budget commitment entailed by) megaproject initiatives, and b) making tradeoffs among research fields in the S&T base. For instance, the broad field of the life sciences has received substantial increases in funding over the last 15 years, while other fields have climbed more slowly. Seen as part of the Federal research portfolio, the life sciences could be stabilized in funding, while certain other fields, ranked according to other criteria (e.g., training of students), could be slated for augmented funding. Already included in most research decisionmaking are criteria based first and foremost on scientific merit. OTA suggests that two other criteria could be added to scientific merit. These criteria emphasize planning for the future—strengthening education and human resources, and building regional and institutional capacity. Education, human resources, and regional and institutional capacity are valid outcomes of Federal research investments. Progress toward achieving national objectives that incorporate these criteria should be monitored with congressional oversight.

Reordering the criteria of choice changes the process and the expectations of returns from the investment in research. Such reconfiguration, perhaps seen most clearly in big science projects, demonstrates how embedded science and technology have become in the myriad needs of the Nation. These initiatives are appropriated by political actors because they are much more than cutting-edge research. They represent ''real money''—in jobs, industrial development, innovation, trade, and prestige regionally, nationally, and internationally. This is why the constituencies for them are broad and why they remain controversial within their respective research communities years after having been proposed and the down payment made by the Federal Government.

Enhanced priority setting could be the 1990s' expression of the post-World War II social contract that bound science to government. However, greater priority setting in science is no panacea for the problem of research funding. It is a partial response to the problem of how the Federal research system can make choices in the coming decade. Another response of comparable urgency—understanding and coping with research expenditures—is discussed in chapter 6.

CHAPTER 6

Understanding Research Expenditures

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CHAPTER 6

Understanding Research Expenditures

> *University research is a smokestack industry. That the research university's capital costs are small and easy to cope with is a myth.*
>
> William F. Massy[1]

Introduction

Many researchers state that the problem with research funding in the United States is that it has not kept pace with inflation. "Inflation" in this context refers not to inflation in the Gross National Product, but to the rise in apparent research costs. Several factors contribute to research expenditures, but the most notable is the sheer size of the enterprise.

Contributing to confusion over the issue of costs in research are the numerous and sometimes inconsistent meanings of "costs," and the lack of a suitable measure of "research." Specific research activities generally become cheaper to complete with time, due to increasing productivity, for example, of computers and other technologies. However, advances in technology and knowledge also allow deeper probing of more complex scientific problems and create demand for greater resources. Because success in the research environment depends heavily on "getting there first," there is clear advantage to having the financial support to acquire additional staff and cutting-edge technology. Thus, competition drives up demand for funding. In this sense, the demand for more resources (costs of research) will continue to outpace any increases in Federal funding. (For a more complete discussion, see chapter 1.)

Available data suggest that an increase in the number of scientists supported by Federal funds combined with real growth in their salaries and benefits have figured heavily into total Federal expenditures.[2] In recent years growth in research budgets (i.e., support) has also been accompanied by a growth in researcher's expectations (i.e., demand). In addition to increased competition through the 1980s for available agency research funding,[3] research expenditures on scientific projects (both direct and indirect) have grown, generally above the rate of inflation. Some claim that research requires more expenditures today because of complexity: what was done yesterday can often be done cheaper today, but "tomorrow's science" may cost more. As understanding of natural and social phenomena increases, the questions to be answered become more intricate, resulting in increased expenditures or "sophistication inflation."[4] Complying with increasing layers of regulation has also been cited as responsible for increased expenditures.[5]

Unfortunately, few systematic analyses have been performed to evaluate these claims. Complicating questions on the cost of research are incomplete and murky data on research expenditures. Definitions of what is being measured over time are straightforward, but the activity that they purport to capture is constantly changing. In addition, much of the current debate over expenditures takes place within the context of agency budget constraints and pressures felt by research performers. Determining what is an adequate amount of Federal money for the conduct of research is not easy, and is only compounded by confusion over true costs.[6]

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[1] William F. Massy, "Capital Investment for the Future of Biomedical Research: A University Chief Financial Officer's View," *Academic Medicine*, vol. 64, August 1989, p. 433.

[2] Researchers are now submitting more proposals to improve their chances of maintaining or increasing previous support levels. National Science Foundation, "NSF Vital Signs: Trends in Research Support FY 80-89," draft report, November, 1990, p. 3. The National Science Foundation (NSF) found that the average number of proposals submitted by an investigator to win one NSF award had risen from about 1.5 to 1.7. NSF notes that these data do not address the extent to which the increase in proposal submissions to NSF is the result of perceived difficulty in winning awards or other factors such as growth in the population of research fields or greater pressure to win awards for professional advancement.

[3] U.S. Congress, Office of Technology Assessment, "Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System," staff paper of the Science, Education, and Transportation Program, April 1990.

[4] *Science: The End of the Frontier?* a report from Leon M. Lederman, president-elect, to the Board of Directors of the American Association for the Advancement of Science (Washington, DC: American Association for the Advancement of Science, January 1991), p. 6; and D. Allan Bromley, "Keynote Address," *Science and Technology and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), p. 11.

[5] National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1990* (Washington, DC: September 1990), p. xvii.

Analysis of expenditures for the conduct of research focuses on what Federal agencies are willing to spend for personnel, facilities, and instrumentation, but gives neither an accurate picture of what the needs are nor whether expenditures are being totally recovered by the research performers.[7] Individual components of the research budget have not risen significantly, with the exception of salaries and fringe benefits. However, more scientists and engineers are doing research; they are getting paid more for their work, and they are spending more. Annual expenditures, including operating, equipment, and capital (facilities) spending per full-time equivalent investigator, are estimated to have increased from $85,000 (1988 dollars) in 1958 to about $170,000 by the late 1960s, where they leveled off through the 1970s. In the 1980s, expenditures rose to $225,000 (see figure 6-1).

Thus, an academic scientist today spends almost three times as much (in real terms) for research as in 1958. Figure 6-2 shows that expenditures have risen in every component (personnel, facilities, equipment, students, other) for three decades. However, available data point to personnel and indirect cost expenditures as the most important components of increases. Personnel expenditures have less accounting flexibility: unlike facilities and instrumentation costs, they cannot be deferred or depreciated.[8] Federally supported academic research is salary intensive. This leads to salaries and fringe benefits affecting the direct cost equation more than nonpersonnel items.

Indirect costs have been rising faster than direct costs. Academic institutions claim that is because the more expensive items, such as facilities and administration, more often fall into the indirect cost category, while controllable expenditures, such as research personnel and graduate students, fall into the direct cost line. The confusion about indirect v. direct costs of research is, in part, complicated by philosophical differences about where expenditures should be assigned. For at least the past 20 years, a debate has been carried on between university administrators and Federal granting agencies over who should pay for what in academic-based research. Although the grant is for research, it is signed with an institution, which incurs expenditures beyond the scope of the research being performed. It has been the practice of the Federal Government to consider research as integral to the university mission and, therefore, its cost should be shared by both parties.[9]

This chapter looks at the issue of research expenditures from two perspectives—the Federal Government as funder, and the research university as performer.[10] Available data concerning specific budget items (e.g., salaries, instrumentation, indirect costs, and facilities) are presented. These data are collected by granting agencies and tend to reflect agency expenditures rather than actual costs to the researcher. Expenditures, as recognized from the perspective of the university research performer, are also discussed as a component of financial planning, proposal-writing strategies, and changing expectations.

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[6] For an illustration, see Daniel E. Koshland, "The Underside of Overhead," *Science*, vol. 248, May 11, 1990, p. 645; and letters, published as "The Overhead Question," in response to Koshland's editorial, *Science*, vol. 249, July 6, 1990, pp. 10-13.

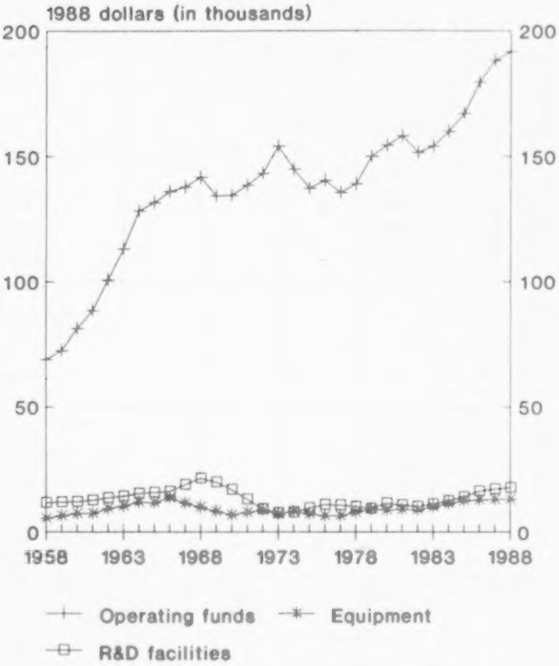
[7] Analysis is confounded by the expenditure accounting schemes that vary from research institution to institution, making comparisons both difficult and perilous. For an attempt to compare expenditures at two public and two private universities associated with the performance of National Science Foundation-funded research, see G.W. Baughman, "Impact of Inflation on Research Expenditures of Selected Academic Disciplines 1967-1983," report prepared for the National Science Foundation and the National Center for Educational Statistics, Nov. 8, 1985. Also see Research Associates of Washington, *Higher Education Price Indexes: 1990 Update* (Washington, DC: 1990).

[8] For at least the fifth consecutive year, faculty salaries have increased more than the cost of living. From November 1989 to November 1990, the consumer price index increased 6.3 percent. During that same period, average faculty pay increased 7.1 percent. Reported in "Faculty Pay and the Cost of Living," chart, *The Chronicle of Higher Education*, vol. 37, No. 17, Jan. 9, 1991, p. A15.

[9] This practice fuels what is known as the "full cost recovery" debate. See Stephen P. Strickland, *Research and the Health of Americans* (Lexington, MA: Lexington Books, 1978).

[10] Expenditures in industrial research are not considered here, but have been addressed in two other OTA reports. See U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990); and *Government Policies and Pharmaceutical Research and Development* (Washington, DC: U.S. Government Printing Office, forthcoming 1991).

Figure 6-1—Academic R&D Expenditures per FTE Investigator by Type of Expenditure: 1958-88
(in thousands of 1988 dollars)

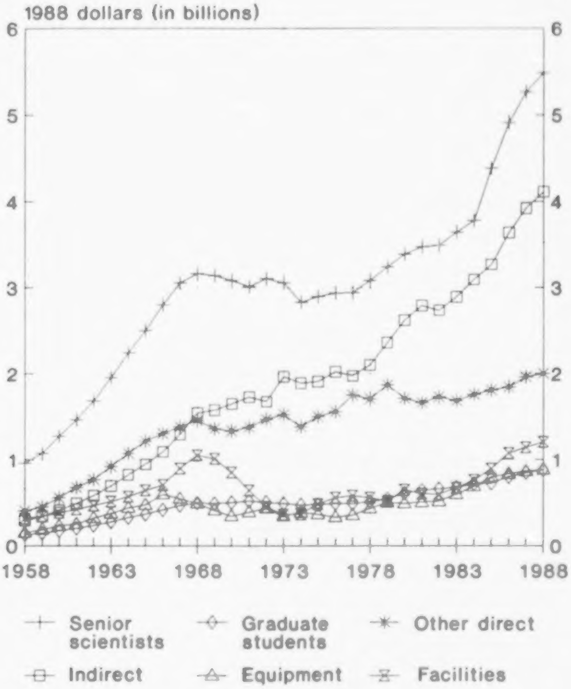


NOTE: Constant dollars were calculated using the GNP Implicit Price Deflator.

DEFINITION OF TERMS: Operating funds refer to current fund expenditures for academic research and development (R&D) activities that are separately budgeted and accounted for, including expenditures for senior scientist and graduate student compensation, other direct costs, and indirect costs associated with conduct of academic research. Equipment includes reported expenditures of separately budgeted current funds for the purchase of academic research equipment, and estimated capital expenditures for fixed or built-in research equipment. R&D facilities include estimated capital expenditures for academic research facilities. Full-time equivalent (FTE) investigators include those scientists and engineers conducting funded (separately budgeted) academic R&D; the FTE is an estimate, derived from the fraction of faculty time spent in those research activities, nonfaculty scientists and engineers employed to conduct research in campus facilities (except federally funded R&D centers), and postdoctoral researchers working in academic institutions.

SOURCE: Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues* (Washington, DC: National Academy Press, 1989), figure 2-45.

Figure 6-2—Estimated Cost Components of U.S. Academic R&D Budgets: 1958-88
(in billions of 1988 dollars)



NOTE: Constant dollars were calculated using the GNP Implicit Price Deflator.

DEFINITION OF TERMS: Estimated personnel costs for senior scientists and graduate students include salaries and fringe benefits, such as insurance and retirement contributions. Other direct costs include such budget items as materials and supplies, travel, subcontractors, computer services, publications, consultants, and participant support costs. Indirect costs include general administration, department administration, building operation and maintenance, depreciation and use, sponsored-research projects administration, libraries, and student services administration. Equipment costs include reported expenditures of separately budgeted current funds for the purchase of research equipment, and estimated capital expenditures for fixed or built-in research equipment. Facilities costs include estimated capital expenditures for research facilities, including facilities constructed to house scientific apparatus.

DATA: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges; National Institutes of Health; American Association of University Professors; National Association of State Universities and Land-Grant Colleges.

SOURCE: Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues* (Washington, DC: National Academy Press, 1989), figure 2-43.

Photo credit: Research Triangle Institute

The cost of complying with regulations of research procedures and equipment is one of a long list of changing expenditures for Federal research. However, indirect costs and salaries are the largest expenditures in federally funded research.

Expenditures From the Federal Perspective

This section explores what is known about research expenditures from the perspectives and databases of two granting agencies—the National Science Foundation (NSF) and the National Institutes of Health (NIH). It also includes a discussion of cost data collected by NSF pertaining to all Federal research and development (R&D) (as that is the level at which the available data are aggregated), as well as analyses conducted by the National Academy of Sciences and other cost analysts.

Direct v. Indirect Costs

The Office of Management and Budget (OMB) guidelines for indirect costs include those that are incurred for common or joint objectives and therefore cannot be identified readily and specifically with a particular sponsored project, an instructional program, or any other institutional activity.[11] Indirect costs reflect the contractual arrangements between the agency and a particular university, regardless of actual expenditures at that university. The rate is negotiated based on allowable charges, past experiences, and expectations for the period under negotiation. The indirect cost ratio is the proportion of total award budget applied to indirect costs. In general, all research agencies pay the same indirect cost rate at a given institution (the Department of Agriculture is the exception in that formulas are used). Direct costs are those that can be identified with a particular sponsored project, instructional program, or any other institutional activity; or that can be directly assigned to such activities with a high degree of accuracy.

The guidelines for calculating costs were developed in conjunction with OMB Circular A-21 and have been in force since 1979. OMB also specifies the method for calculating the indirect portion of salaries and wages paid to professional employees. A requirement exists for assigned workload to be incorporated into the official records and for that system to reflect 100 percent of the work for which the employee is being compensated.[12] Thus, the record should show the percentage of time spent on research, teaching, and administrative duties.

Every major research university has an indirect rate established for the current fiscal year for recovery of costs associated with sponsored research. These rates have evolved over many years as a result of direct interaction and negotiation with the cognizant Federal agency. There is a wide range of indirect cost rates among universities, with most noticeable differences between public and private institutions; rates tend to be higher at private institutions.[13] Rates vary because of: 1) real and significant differences in facilities-related expenditures, 2) tacit or overt underrecovery by some universities, 3) imposition of arbitrary limits by

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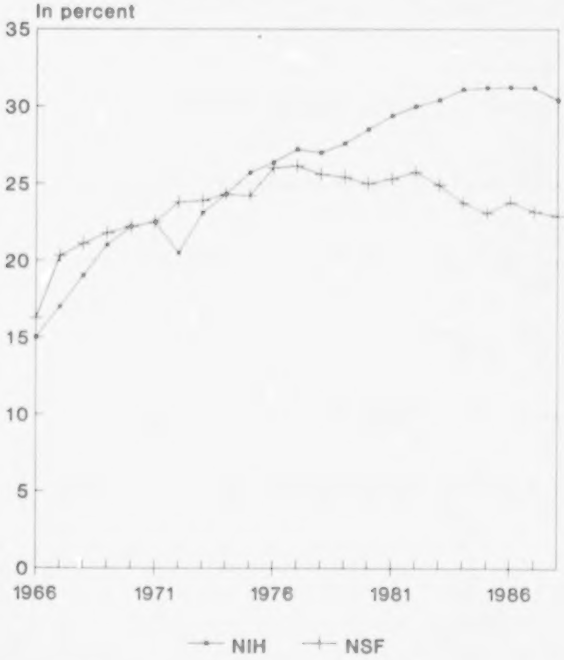
[11] U.S. Department of Commerce, Bureau of Economic Analysis, *Biomedical Research and Development Price Index: Report to the National Institutes of Health* (Washington, DC: Mar. 30, 1990).

[12] Ibid., p. 18. Also see U.S. Congress, Office of Technology Assessment, *The Regulatory Environment for Science*, OTA-TM-SET-34 (Springfield, VA: National Technical Information Service, February 1986), pp. 73-76.

[13] Rep. John Dingell's Energy and Commerce Subcommittee on Oversight and Investigations launched in late fall 1990 an investigation of indirect cost practices at universities, beginning with Stanford. See Marcia Barinaga, "Stanford Sails Into a Storm," *Science*, vol. 250, Dec. 21, 1990, p. 1651; "Government Inquiry," *Stanford Observer*, November-December 1990, pp. 1, 13; and Marcia Barinaga, "Indirect Costs: How Does Stanford Compare With Its Peers," *Science*, vol. 251, Feb. 15, 1991, pp. 734-735.

Figure 6-3—Indirect Cost Ratios for NSF and NIH: 1966-88 (Indirect cost as a percent of total R&D cost)



KEY: NIH=National Institutes of Health; NSF=National Science Foundation.

SOURCE: National Science Foundation, Policy Research and Analysis Division, estimates based on unpublished NIH and NSF data, 1990.

Photo credit: University of Michigan

Indirect cost rates vary in part because of differences in campus facilities. The University of Michigan, pictured here, devotes many of its facilities to research.

some government agencies in the negotiation process, and 4) diversity in assigning component expenditures as direct or indirect.[14]

Figure 6-3 indicates the trends in indirect costs as a proportion of total research expenditures for NIH and NSF. In part, the ratios vary because NIH separates direct and indirect costs, and proposals are evaluated based mainly on direct costs. NSF, on the other hand, considers total costs in making an award (usually after merit review).

Confusion about the relationship between the indirect cost rate and what is allowable for administrative and student service components reflects the difficulty of separating expenditures along lines of research, instruction, and other functions.[15] Equipment and facilities-related components of the rate seem to be less controversial, perhaps because of better documentation of expenses in these areas. Some have advocated that two rates should be calculated for indirect costs—one for facilities and equipment, and one for all other components, such as administrative, library, and student services.[16] This view has considerable relevance as universities renovate or replace aging facilities and equipment.

Aggregate Expenditure Data for Personnel, Facilities, and Equipment

Expenditures for facilities and equipment are frequently cited as a drain on the academic financial resource base. These data, however, mix actual and planned expenditures. As universities compete against industry and each other for resources, funding needs grow, as does spending. Competition in the university environment has also driven up the "set up" price of the average scientist.[17] Data on salaries and personnel are more reliable because these cost categories cannot be deferred and are documented annually.

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[14] Association of American Universities, *Indirect Costs Associated With Federal Support of Research on University Campuses: Some Suggestions for Change* (Washington, DC: December 1988).

[15] Eleanor C. Thomas and Leonard L. Lederman, Directorate for Scientific, Technological, and International Affairs, National Science Foundation, "Indirect Costs of Federally Funded Academic Research," unpublished report, Aug. 3, 1984, p. 1.

[16] Association of American Universities, op. cit., footnote 14.

[17] The Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington, DC: National Academy Press, 1989), p. 2-33.

Personnel

For the past three decades, personnel expenditures have accounted for about 45 percent of total costs of academic research charged to the Federal Government, consistently the largest share of the budget. Salaries have been on the rise and from 1981 to 1988 the number of scientists and engineers employed in academic settings increased steadily from about 275,000 to almost 340,000.[18] Increased numbers of investigators and rising salaries (and the benefits that go with them) have driven up the price of the personnel component of direct costs. In future years, it is anticipated that the personnel component of research budgets will rise further due to a faster rate of inflation in salaries than in other categories such as equipment and facilities.[19] And the fiscal year 1991 appropriation for NSF lifted the $95,000 annual salary cap on principal investigators that can be charged to a grant.[20]

The patterns for spending on graduate students mirror that for principal investigators. Increases in the number of graduate students supported, however, were larger than the growth in the number of scientists due to a greater reliance on the research grant as a support mechanism.[21]

Research Facilities Construction and Renovation

Research facilities may be defined as the environment within which research is conducted, as opposed to research instruments, or the tools that scientists and engineers use to collect data. Facilities currently receive about 10 percent of the Federal R&D budget compared to about 6 percent at the beginning of the 1980s.[22] Most of the data available on scientific and engineering research facilities are collected by NSF on a biennial basis in response to the 1986 National Science Foundation Authorization Act (Public Law 99-159). The act required NSF to design, establish, and maintain a data collection and analysis capability for the purpose of identifying and assessing the research facilities needs of universities and colleges. Data are not available before 1986. The assessments are based in part on estimates, relying on reported capital projects—both actual and planned—and anticipated spending for construction and repairs of research facilities.[23] Actual expenditure data are derived from expenditures in previous years.

In constant 1988 dollars, annual capital expenditures for academic science and engineering facilities nearly tripled during the ''golden age'' from $1.3 billion in 1958 to $3.5 billion a decade later. Expenditures dropped to $1 billion in 1979 (1988 dollars) and stand at $2 billion in 1988. Presently, the Federal share of facilities funding is 11 percent, down from a high of 32 percent in the 1960s.[24]

In 1986-87, academic institutions initiated major repair and renovation projects in academic research space totaling $840 million. In 1988-89, this figure rose to $1.04 billion.[25] Estimated deferral rates for repair and renovation are $4.25 for every dollar spent in 1990, up from $3.60 in 1988.[26]

Institutions' spending for *new* construction of research facilities was expected to grow from $2.0 billion in 1986-87 to $3.4 billion in 1988-89, an average increase of about 30 percent per year.[27] A 1990 update revealed that costs for 1988-89 new

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[18] Ibid., p. 2-34, based on National Science Foundation data.

[19] National Science Foundation, *The State of Academic Science and Engineering* (Washington, DC: 1990), pp. 119-149. Of course, personnel expenditures would be much higher if full salary and fringe benefits were charged to the Federal Government. Most universities absorb a substantial portion of such expenditures. Some agency programs will pay for only 2 to 3 summer months. Leonard Lederman, Directorate for Scientific, Technological, and International Affairs, National Science Foundation, personal communication, December 1990.

[20] ''NSF Back To Normal After Budget Pause,'' *Chemical & Engineering News*, vol. 68, No. 48, Nov. 26, 1990, p. 12.

[21] National Science Foundation, op. cit., footnote 19, pp. 124-125.

[22] Ibid., pp.134-139.

[23] According to National Science Foundation commentators on this October 1990 OTA draft chapter, estimates of ''need'' denote deferral of facilities expenditures (both new construction and repair/renovation projects), not an institutional ''wish list.'' National Science Foundation staff, personal communication, December 1990.

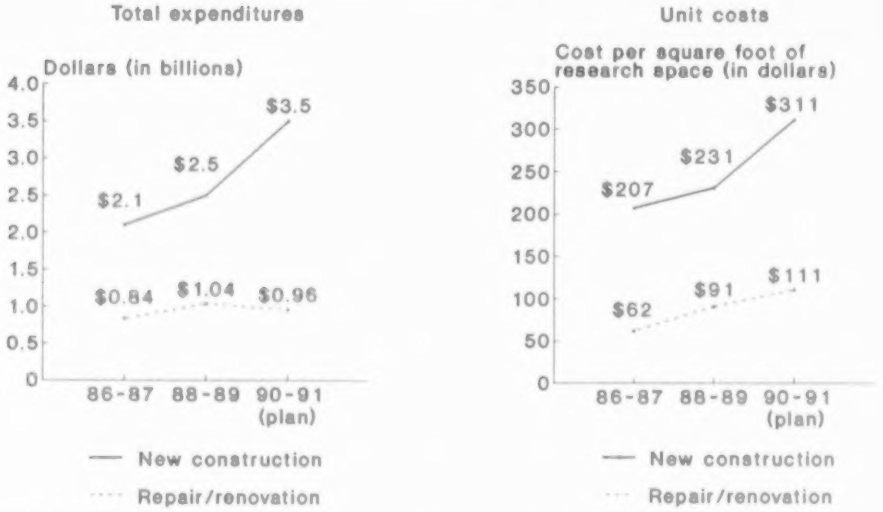
[24] Government-University-Industry Research Roundtable, op. cit., footnote 17, pp. 2-28, 2-29.

[25] National Science Foundation, op. cit., footnote 5, p. xvii.

[26] Ibid., p. xix.

[27] National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1988* (Washington, DC: September 1988).

Figure 6-4—Total Expenditures and Unit Costs for Recent and Planned Academic Capital Projects: 1986-91



NOTE: Estimates of research space are based on net assignable square feet assigned to organized research.

SOURCE: National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1990*, final report, NSF 90-318 (Washington, DC: 1990), chart 4, and p. A-10.

construction projects totaled only $2.5 billion, considerably less than projected.[28] Private institutions among the top 50 recipients of Federal R&D funds report considerably higher spending levels than public institutions, both for construction and repair and renovation. The reverse is true among institutions not in the top 50, where spending levels are higher at public institutions.[29]

The unit cost of new construction (the cost per net square foot) grew in real terms from $207 in 1986-87 to $231 in 1988-89, an increase of about 12 percent per year (see figure 6-4). Construction expenditure increases of this magnitude, which are above the rate of inflation, are attributed in part to changing technical and regulatory requirements such as animal quarters,[30] biohazard containment safeguards, and toxic waste disposal facilities. These regulatory requirements are especially relevant to the medical and biological sciences, but vary with the institutional setting in which the research is conducted.[31]

The proportion of Federal support for construction is about 11 percent in private institutions and 8 percent in public institutions (see figure 6-5). The Federal Government also pays for renovation and repair costs in part through the indirect cost rate, and in 1988, the Federal Government supplied nearly $1 billion to support university infrastructure through indirect costs. Almost 20 percent was for facilities depreciation, while the rest was recovered for

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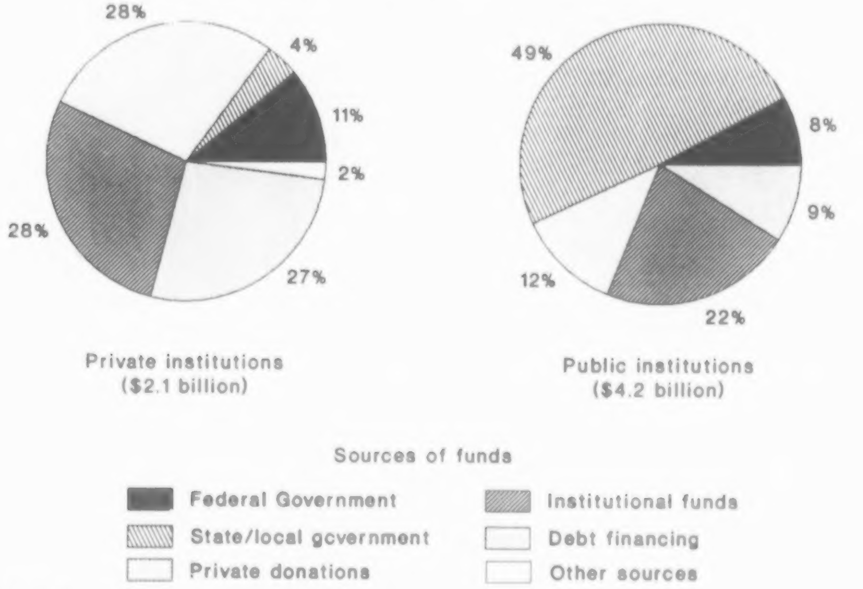
[28] National Science Foundation, op. cit., footnote 5. The report suggests that inability to obtain sufficient funding was the principal reason given by institutions for postponing or scaling back planned construction projects.

[29] Ibid., pp. 19-24.

[30] The Alcohol, Drug Abuse, and Mental Health Administration estimates that new regulations for animal care will cost $40,000 to $70,000 per grant for the care of primates and dogs. See Constance Holden, "A Preemptive Strike for Animal Research," *Science*, vol. 244, Apr. 28, 1989, pp. 415-416. An American Association of Medical Colleges survey of 126 medical schools estimated that animal rights activities cost U.S. medical schools approximately $17.6 million for increased security, insurance, recordkeeping, and compliance over the last 5 years; as reported in *Washington Fax*, July 23, 1990.

[31] Office of Technology Assessment, op. cit., footnote 12, pp. 85-96. Also see Philip H. Abelson, "Federal Impediments to Scientific Research," *Science*, vol. 251, Feb. 8, 1991, p. 605. Abelson estimates that the Federal Government imposed more than 23 administrative reporting requirements on universities during the 1980s.

Figure 6-5—Relative Sources of Funds for Research Facilities: Academic Capital Projects Begun in 1986-89



NOTE: Percentages may not total 100 due to rounding.

SOURCE: National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1990*, final report, NSF 90-318 (Washington, DC: 1990), chart 6.

operation and maintenance costs.[32] In absolute terms, Federal funds for new construction of research space more than doubled over the 1986 to 1989 period, and the increase was seen primarily at public institutions.

Equipment and Instrumentation

There is one comprehensive source of data on research equipment and instrumentation expenditures. The National Survey of Academic Research Instruments and Instrumentation Needs is a congressionally mandated, triennial survey program to monitor trends in academic research. It is sponsored jointly by NIH and NSF, and has been completed twice, first in 1983-84 and again in 1986-87.[33] A new survey is in progress. The survey collects data about expenditures, funding, and use of major research instruments (costing $10,000 to $1 million) in engineering, and in the agricultural, biological, computer, environmental, and physical sciences. Information is collected about both quantitative and qualitative changes in in-use instrumentation and equipment.

Results from these surveys show that there is substantial turnover in the national stock of in-use academic research equipment. About one out of every four systems in research use in 1982-83 was no longer being used for research by 1985-86, and about two out of five systems in research use in 1985-86 had been acquired in the 3-year period since the baseline data were obtained.[34] Computer science had the most rapid rate of expansion in stock (up 138 percent over the 1982 to 1986 period), with slow

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[32] Facilities have contributed greatly to the rising indirect cost reimbursements. Over the period 1982 to 1988, the Federal support of university infrastructure through indirect cost recovery grew by over 70 percent in real terms. See "Enhancing Research and Expanding the Human Frontier," *Budget of the United States Government, Fiscal Year 1992* (Washington, DC: U.S. Government Printing Office, 1991), pp. 61-62. This document further states that: "Each academic institution must provide a certification that its research facilities are adequate (to perform the research proposed) as a condition of accepting research grants. . . . [The] $12 billion of needed, but unfunded capital projects has not had an apparent effect on the ability of universities to accept Federal research funds." The $12 billion estimate comes from the 1990 National Science Foundation survey of universities.

[33] National Science Foundation, *Academic Research Equipment in Selected Science/Engineering Fields: 1982-83 to 1985-86*, SRS 88-D1 (Washington, DC: June 1988).

[34] Ibid.

Photo credit: Jay Mangum Photography

Researcher uses a CT scanner. State-of-the-art equipment often enables researchers to push the frontiers of scientific knowledge.

growth in mechanical engineering (up 23 percent) and materials science (22 percent). The data indicate that Federal and non-Federal expenditures for academic research equipment increased from $393 million (1982 dollars) in 1980 to $704 million in 1987.[35] Yet the mean purchase price per system for all in-use equipment in 1985-86 was $36,800, basically unchanged from 1982-83 (up only 1 percent after inflation). Computer science was the only field to show a substantial real change in the mean price per unit of in-use instrumentation, dropping 22 percent after adjusting for inflation.[36]

Federal involvement in funding academic research equipment declined somewhat from 1982-83 to 1985-86. Fifty-five percent of all systems in use in 1986 were acquired either partly or entirely with Federal funding support, down from 60 percent in 1982-83. Despite this relative decline, Federal support for in-use research equipment increased 30 percent in real dollar terms, from $663 million in 1982-83 to $906 million in 1985-86.[37] Data for select Federal funding sources are displayed in table 6-1. Not unexpectedly, funding for equipment under development, or considered state-of-the-art, grew at higher rates than existing systems. Qualitative upgrading (e.g., incremental improvement in the power and capability of existing equipment), however, varies across fields, e.g., chemistry experienced more upgrading than agricultural sciences.

Despite pronounced increases and improvements in equipment stocks in the 1980s, 36 percent of department heads still describe their equipment as inadequate (to conduct state-of-the-art research). In general, the survey data reveal that equipment stocks have been substantially replenished and refurbished during the period of 1982 to 1986 in all of the fields studied and in all types of institutions. There have been substantially increased levels of support for instrumentation from all sources, with most of this increased support coming from the colleges and universities themselves, as well as from businesses, private donors, and State governments. In relative terms, computer science was the greatest beneficiary of the overall increase in instrumentation support, particularly from Federal sources, with engineering suffering the most. Among all Federal sources of equipment support, NSF provided the largest share (33 percent of the total).[38]

Within the biological sciences, biochemistry more than doubled its equipment stocks between 1984 and 1987, the fastest rate of growth of any major biological field. There appears to be an increasing need in the biological sciences for big-ticket items costing over $50,000 (1984 and 1987 prices for some items are shown in table 6-2). The percentage of department heads reporting equipment in this range as being their top priority for more Federal funding increased from 20 percent to 35 percent from 1984 to 1987.[39]

Expenditures for equipment were $200 million (1988 dollars) in 1958, rose to $600 million in the 1960s, fell to below $400 million in the 1970s, and

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[35] Ibid., p. 17.

[36] Some universities, however, spend more on equipment than others. The top 20 research and development universities had in stock an average of $27.9 million worth of inuse equipment in the 1985-86 academic year. The average for the next 154 institutions was $6.9 million. National Science Foundation, 1989, op. cit., footnote 19, pp. 130-133.

[37] National Science Foundation, op. cit., footnote 33, p. 17.

[38] Federal agencies provided 46 percent of the funding for biological science equipment use in 1987; the National Institutes of Health provided 76 percent of the Federal share. Ibid., pp. 59-64.

[39] U.S. Department of Health and Human Services, National Institutes of Health, *Academic Research Equipment and Equipment Needs in the Biological Sciences: 1984-1987* (Washington, DC: June 1989), pp. 8-1 through 8-10.

Table 6-1—Selected Sources of Funding for 1985-86 National Stock of In-use Research Equipment and Percent Change From 1982-83,[a] by Field (in millions of 1985-86 dollars)

Field	Total research equipment	NSF	NIH	DOD	DOE	State/ university funds	Business donations
Computer science	$100 (85%)	$26 (123%)	$1 (UE)	$20 (99%)	<$1 (UE)	$25 (38%)	$20 (61%)
Engineering:	372 (34%)	38 (1%)	5 (UE)	59 (16%)	17 (15%)	135 (35%)	81 (47%)
Electrical	110 (59%)	11 (4%)	1 (UE)	23 (11%)	2 (UE)	30 (142%)	36 (187%)
Mechanical	71 (32%)	7 (–12%)	<1 (UE)	16 (23%)	1 (UE)	28 (66%)	13 (52%)
Other	191 (23%)	20 (5%)	5 (UE)	20 (18%)	14 (45%)	78 (10%)	32 (43%)
Materials science	44 (26%)	19 (33%)	<1 (UE)	3 (UE)	4 (UE)	11 (23%)	2 (UE)
Physics/astronomy	221 (16%)	54 (1%)	1 (UE)	28 (13%)	29 (0%)	50 (88%)	14 (2%)
Chemistry	322 (44%)	85 (22%)	32 (64%)	.15 (54%)	17 (186%)	111 (38%)	28 (78%)
Environmental sciences	170 (47%)	30 (71%)	1 (UE)	10 (44%)	15 (70%)	56 (50%)	27 (39%)
Agricultural sciences	62 (61%)	4 (UE)	2 (UE)	<1 (UE)	1 (UE)	39 (55%)	6 (UE)
Biological sciences:	643 (48%)	51 (39%)	226 (44%)	7 (UE)	4 (UE)	247 (54%)	48 (53%)
In colleges/universities	283 (63%)	32 (26%)	79 (51%)	5 (UE)	2 (UE)	123 (89%)	19 (45%)
In medical schools	360 (389%)	19 (66%)	148 (41%)	2 (UE)	2 (UE)	124 (31%)	29 (59%)

[a] Percent change estimates are adjusted for inflation.

KEY: NSF = National Science Foundation; NIH = National Institutes of Health; DOD = U.S. Department of Defense; DOE = U.S. Department of Energy; UE = unstable estimate: 1982-83 base is less than $4 million.

SOURCE: National Science Foundation, *Academic Research Equipment in Selected Science/Engineering Fields: 1982-83 to 1985-86* (Washington, DC: June 1988), table A.

Table 6-2—Types and Expenditures for Most Needed Research Equipment: National Estimates for the Biological Sciences, 1984 and 1987[a]

Types of system	Percent of requests		Median cost per system	
	1984	1987	1984	1987
Preparative (e.g., centrifuges, scintillation counters, incubators)	33%	25%	$30,000	$35,000
Protein/DNA sequencers/ synthesizers	11	14	75,000	95,000
Electron microscopy	12	6	150,000	180,000
Light microscopy	4	3	30,000	35,000
High-pressure liquid chromatography	9	12	27,000	25,000
Cell sorters/counters	4	6	150,000	100,000
MNR spectroscopy	4	4	250,000	225,000
General spectroscopy	9	5	25,000	30,000
Mass spectroscopy	2	4	125,000	100,000
Image analyzers	3	6	40,000	100,000
X-ray (other than imaging)	1	1	100,000	200,000
Computers	5	5	50,000	45,000
Other	6	9	30,000	45,000

[a] Findings are based on department chairs' listings of up to three "topmost priorities" in research instruments or systems.

SOURCE: National Institutes of Health, *Academic Research Equipment and Equipment Needs in the Biological Sciences: 1984-87* (Washington, DC: June 1989).

were over $800 million in 1988. The Federal share of funding was 75 percent in 1958 and now stands at about 60 percent.[40] NSF found that instrumentation costs have increased (in real dollars) for state-of-the-art instruments, but costs for instruments of similar capability have been decreasing. In addition, obsolescence time was 7 to 10 years in 1975, while the 1986 estimate was 3 to 5 years. And these instruments require funds for maintenance and operation (about 4 percent of the purchase price).[41]

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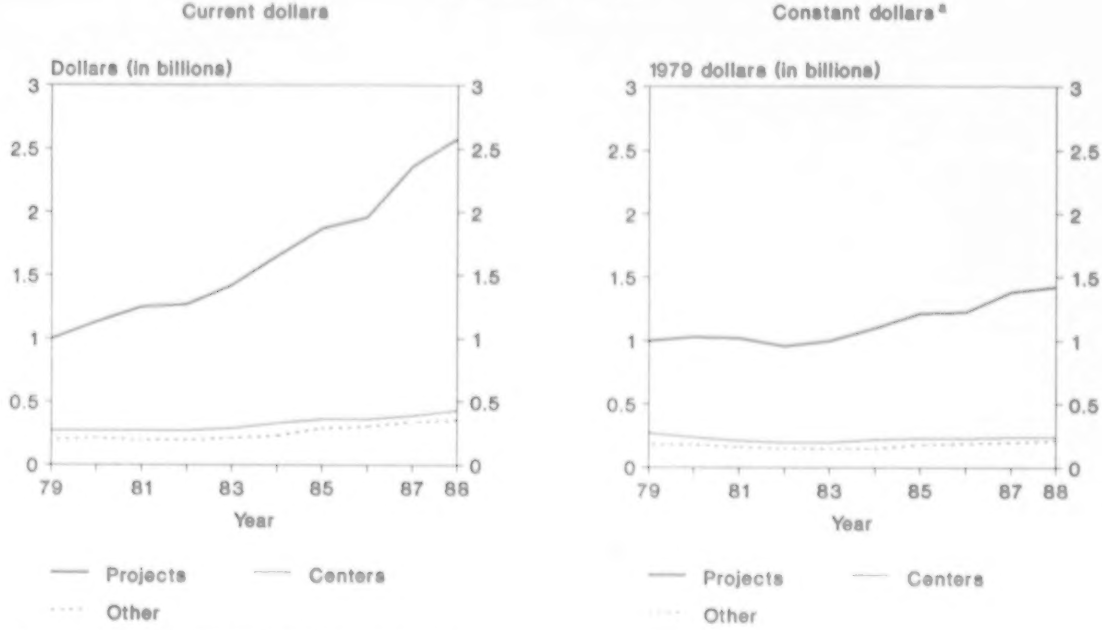
[40] Government-University-Industry Research Roundtable, op. cit., footnote 17, p. 17.

[41] National Science Foundation, op. cit., footnote 19, pp. 130-133. The enhanced power or sophistication of a new instrument, say, an automated DNA sequencer, is seen by researchers as justifying its cost, which is a relatively modest investment for sustaining, or perhaps enabling for the first time, the performance of frontier science. As Robert Borchers, associate director for computation at Lawrence Livermore National Laboratory, puts it: "We're scientists. When we hear about a faster machine, we're interested." Quoted in Marcia Clemmit, "Livermore's Purchase of Japanese Supercomputer Is Blocked," *The Scientist*, vol. 4, No. 23, Nov. 26, 1990, p. 3.

Figure 6-6—Direct Costs Awarded for NIH Research Projects, Research Centers, and Other Research Grants: Fiscal Years 1979-88



[a] Based on the biomedical R&D price index, fiscal year 1979=100.
KEY: NIH=National Institutes of Health.
SOURCE: National Institutes of Health, *Extramural Trends: FY 1979-1988* (Washington, DC: June 1989), p. 18.

University researchers echo the same concerns about research expenditures for equipment: 1) instrumentation is becoming obsolete at a faster rate; 2) many are buying more computer equipment or using a universitywide computer system (for example, the University of Michigan spends over $160 million every year on information systems—10 percent of its operating expenses); 3) most research fields are becoming increasingly dependent on advances in research equipment; 4) support personnel are required in increasing numbers to operate equipment; and 5) maintaining research equipment for a laboratory takes a large amount of researcher time.[42]

Research Expenditures at the National Institutes of Health

The amount of dollars awarded for direct costs of individual investigator-initiated, or RO1, research at NIH has risen steadily since 1979. The direct costs in current dollars awarded that year increased by $1.5 billion, or 155 percent, to a fiscal year 1988 all-time high of $2.6 billion (see figure 6-6). In constant dollars, growth was $408 million, or a net increase of 41 percent. According to NIH's Division of Research Grants, the proportion of indirect costs to total expenditures has increased in 8 of the years from 1979 to 1989, ranging from just under 28 to over 31 percent. Nevertheless, when examining dollars awarded, and controlling for inflation, indirect costs are rising at a faster rate than direct costs (20 percent higher).

Personnel expenditures accounted for 65 percent of the $3.2 billion direct costs budgeted for fiscal year 1988 RO1 research. The next largest category of direct costs was supplies, at 12.4 percent. The equipment category has been stable at 5.2 to 5.6 percent since 1984 (see table 6-3). Noncompeting and competing continuation grants have higher expenditures for personnel than do new grants (68 and 64 percent, respectively, v. 51 percent for new

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[42] From OTA interviews at University of Michigan and Stanford University, July-August 1990.

Table 6-3—Extramural Direct Costs by Budget Category at NIH: Fiscal Years 1979-88

Fiscal year	Total direct costs (in billions of dollars)	Personnel (in percent)	Equipment (in percent)	Supplies (in percent)	All other (including hospitalization, in percent)
1979	$1.4	66.8%	6.2%	13.0%	14.0%
1980	1.5	67.8	5.2	13.2	13.8
1981	1.6	68.4	4.5	13.4	13.7
1982	1.7	69.5	4.4	12.7	13.4
1983	1.9	69.4	4.8	12.7	13.1
1984	2.1	68.5	5.2	13.1	13.2
1985	2.4	66.5	5.9	12.7	14.9
1986	2.6	67.8	5.3	11.6	15.3
1987	3.0	65.8	5.8	12.0	16.3
1988	3.2	64.9	5.6	12.4	17.1

SOURCE: National Institutes of Health, *Extramural Trends: FY 1979-1988* (Washington, DC: June 1989), p. 61.

grants). Conversely, equipment expenditures are higher for new grants than for continuations.

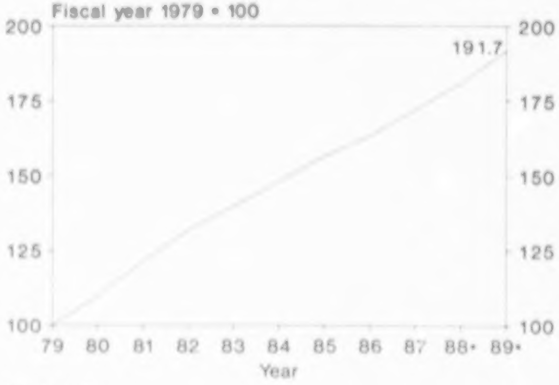
In recent years, NIH has conducted "downward negotiations" of noncompeting grant continuations, whereby the amount awarded in years after the initial award will be less than the original commitment.[43] This practice has resulted in uncertainty for the investigator as to what funding will be available from year to year.[44] It has also led to congressional criticism of financial planning at NIH (see box 6-A).

Calculating the Biomedical Research and Development Price Index

The Biomedical Research and Development Price Index (BRDPI) is a specialized price index calculated since 1979 by the Bureau of Economic Analysis of the Department of Commerce for NIH. The BRDPI is a fixed-weight index designed to reflect price changes of the cost to NIH of supporting biomedical R&D. The index is calculated for fiscal years and is currently based on patterns of NIH obligations for fiscal year 1988[45] (see figure 6-7).

The BRDPI is comprised of three major subindices—intramural activities, extramural activities, and extramural nonacademic activities. Within each activity, price indices are available for major components such as personnel, supplies, and equipment. Intramural activities comprise all activities performed by NIH, including R&D, as well as support functions for intramural and extramural research. Intramural activities are grouped into 27 categories that correspond to available price measures.

Figure 6-7—Biomedical Research and Development Price Index: Fiscal Years 1979-89



aProjected.

SOURCE: National Institutes of Health, *NIH Data Book: 1989* (Washington, DC: December 1989), inside back cover.

Figure 6-8 shows a comparison of the aggregate BRDPI with three other indices—the Consumer Price Index, the Producer Price Index, and the Gross National Product. The BRDPI has consistently increased at a faster rate than the other three indices, but has slowed in recent years. Table 6-4 displays the BRDPI for the years 1979 through 1989 (fiscal year 1988 is the base). In 1989, the index is highest for

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[43] Marvin Cassman, "Issues Behind the Drop in the NIH Award Rate," *ASM News*, vol. 56, September 1990, pp. 465-469. Late in 1990, the National Institutes of Health began consideration of a plan whereby funding adjustments would be made prior to award and not through across-the-board cuts.

[44] In contrast, the National Science Foundation awards a set amount for the grant over a multiyear period. Any cuts in the awards are across-the-board, leading to less uncertainty for the grantees. Uncertainty has two distinct but related repercussions for principal investigators: first, their anxiety level is raised regarding available monies for carrying out the next year's work under a multiyear grant, and second, their planning for needed personnel and infrastructure must include several contingencies.

[45] Bureau of Economic Analysis, op. cit., footnote 11, p. 1.

Box 6-A—Financial Planning at NIH: A Congressional Mandate

During its review of the fiscal year 1991 budget for the National Institutes of Health (NIH), the House Committee on Appropriations stated that:

> . . . despite large increases in funding for the NIH during the last decade, the system of Federal support for the health sciences is in crisis. While the Committee believes that this crisis has been overstated, it recognizes that problems with low numbers of new grants, high levels of downward negotiation of grant awards, and the general lack of stability in government support for the biomedical sciences are critical problems which must be addressed if the vitality and the morale of the research community are to be restored.[1]

Thus Congress, as it traditionally has done, gave NIH more than the Administration had requested for 1991, boosting its appropriation to $8.3 million. But the House and Senate appropriations bills, using similar language, ". . . excoriated NIH administrators for inadequate financial planning."[2]

In response to this congressional criticism, NIH drafted a plan for managing biomedical research costs. It was circulated among scientific societies and university associations prior to a December 17, 1990, meeting of the NIH Director's Advisory Committee to register responses to the plan. Twenty witnesses testified. The NIH plan features six goals:

1. Set 4 years as the average length of research project grant awards. Four years would allow NIH to provide funding continuity to investigators while ensuring that a greater number of competing awards are made each year.
2. Implement cost management measures so that the average cost of research project grants increases at the same rate as the Biomedical Research and Development Price Index (BRDPI).
3. Stop using the concept of "approving" grant applications and adopt the "success rate" method based on the ratio of applications funded to applications reviewed—a method used by other Federal agencies.
4. Fund the number of research training grants recommended by the National Academy of Sciences to the extent possible without jeopardizing NIH's ability to provide stipend increases for research trainees.
5. Manage the growth of NIH research centers by controlling NIH appropriations for centers rather than by establishing a ceiling on the number of centers.
6. Increase funding for other mechanisms to reflect inflation.[3]

As pointed out by John Briggs, deputy director of extramural research at NIH, who chaired the December 17 meeting:

> NIH must remain flexible enough to allow biomedical science to respond to public health emergencies and scientific opportunities, and this is reflected in the plan. In order for NIH to carry out its mission, each institute and center must maintain a balanced research portfolio with an appropriate combination of research project grants, center grants, training grants and other mechanisms. Cost management goals can and should be pursued through a combination of peer review actions and administrative controls.[4]

Responses to the NIH plan have been mixed.[5] While increases in research project (RO1) grants are attributable to increases in indirect costs, ". . . neither NIH officials nor researchers can pinpoint specific causes for the increase."[6] Linking indirect costs to the BRDPI is more popular than taking a ". . . total-cost restraint approach."[7]

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[1] U.S. Congress, House Committee on Appropriations, *Departments of Labor, Health and Human Services, and Education, and Related Agencies Appropriation Bill*, report 101-591, 101st Cong. (Washington, DC: U.S. Government Printing Office, July 12, 1990), p. 51.

[2] David L. Wheeler, "NIH Plan Would Trim Length and Growth of Research Grants," *The Chronicle of Higher Education*, vol. 37, Dec. 12, 1990, p. A21.

[3] Based on "NIH Answers Congress With Six-Point Plan," *Washington Fax*, Dec. 18, 1990, p. 1.

[4] Ibid., pp. 1-2.

[5] Based on responses to a survey conducted by *Washington Fax* and reported Dec. 14 and 17, 1990, 80 percent of the respondents favor a single, agencywide policy for implementing Congress's 4-year plan for cost management at the National Institutes of Health.

[6] "Indirect Cost Prime Source of Increase in Dollars for RO1 Grants," *Washington Fax*, Dec. 7, 1990, p. 1.

[7] *Washington Fax*, Dec. 17, 1990. Opposition to study section consideration of indirect costs is nearly unanimous. See "NIH To Focus on Quality Over Numbers," *Washington Fax*, Dec. 19, 1990, p. 1.

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Box 6-A—Financial Planning at NIH: A Congressional Mandate—Continued

Developing a financial management plan is prudent for any agency; adopting and implementing one is more difficult.[8] At a December 18, 1990, meeting the NIH Director's Advisory Committee agreed that stabilizing NIH at 6,000 new and 24,000 total grants should be a "... target rather than a mandate." Some have noted that inflation would reduce NIH's capacity to pay for 6,000 new grants each year, and that aiming for such a total would only perpetuate the current budget problems, a "... dynamic of fat years and lean years."[9]

The committee's draft document will be reviewed by various NIH boards and councils during the first 2 months of 1991, prior to a presentation at congressional hearings in the spring. Many biomedical scientists fear that the grant pool would not be sustainable without sacrifices in facilities, equipment, and training, and that "... no sector of biomedical science should be cannibalized to serve another sector."[10]

Amidst the claims that Congress is micromanaging by calling for expenditure containment at NIH, the language of appropriations is unequivocal. If financial planning does not improve, more radical options exist, including agency-specific limits on the indirect costs that the Federal Government will pay.[11] This story will most likely unfold well into the fiscal year 1992 appropriations process.

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[8] In the absence of a permanent National Institutes of Health director, developing a financial management plan was seen by many as inappropriate. As Jerold Roschwalb, director of Federal relations for the National Association of State Universities and Land-Grant Colleges, puts it: "It may be good politics, it may be good appropriations, and it may be good mathematics, but it could lead to poor science." Quoted in Wheeler, op. cit., footnote 2, p. A21.

[9] Quoted in David L. Wheeler, "Scientists' Complaints Prompt Revisions in NIH Cost-Cutting Plan," *The Chronicle of Higher Education*, vol. 37, No. 17, Jan. 9, 1991, p. A19. The director of the National Institutes of Health's (NIH) division of financial management has found, through computer modeling of the budget, that NIH could support 6,000 new grants per year if its congressional appropriations increased in the range of 7 to 9 percent annually. But "... not everyone thinks that it's a good idea to set an annual goal and give it precedence over NIH-initiated projects, grants to large groups and institutional centers, and other forms of research support." Jeffrey Mervis, "NIH Debates Merit of Setting Grant Minimum," *The Scientist*, vol. 5, No. 2, Jan. 21, 1991, p. 1. In this same article, acting NIH Director William Raub notes (p. 4) that: "In the course of making our annual budget request to Congress, the use of the number of new and competing grants that it would fund has been a powerful tool. Perhaps because they do not understand the details of our enterprise, the committees [that oversee NIH's budget] have found it very useful to think in terms of the number of pieces of research that they are funding. And that information is reflected in the level of new grants." Also see Elizabeth Pennisi, "Budget Increase for NIH Won't Meet Expectations," *The Scientist*, vol. 5, No. 5, Mar. 4, 1991, pp. 1, 6.

[10] See *Washington Fax*, Dec. 14, 1990, p. 1. For fuller descriptions of this meeting and specific points of contention, see Barbara J. Culliton, "Biomedical Funding: The Eternal 'Crisis'," *Science*, vol. 250, Dec. 21, 1990, pp. 1652-1653; and Pamela Zurer, "Research Funding: NIH Airs Cost-Containment Plan," *Chemical & Engineering News*, vol. 68, No. 52, Dec. 24, 1990, pp. 4-5. Clearly, the issue of numbers of grants cannot be decoupled from the duration or average grant amount.

[11] For a discussion of various options, see Barbara J. Culliton, "NIH Readies Plan for Cost Containment," *Science*, vol. 250, Nov. 30, 1990, pp. 1198-1199.

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extramural activities, specifically nonpersonnel (supplies, travel, and consultants) and indirect costs. More telling is table 6-5, which compares percent changes from prior fiscal years for 1980 through 1989. This table shows general slowing of the increase in all areas, but most significantly in indirect costs for extramural activities.

Intramural expenditures have increased at a much slower rate than extramural expenditures, due to the modest increases in Federal employees' pay.[46] Increases in intramural expenditures appear to be leveling off from the sharp increases of the early 1980s (see figure 6-9). The aggregate extramural activities index has slowed to about a 5.5 percent annual increase heading into the 1990s. Extramural activities comprise R&D outside of NIH and financed by grants to universities and medical schools. A sample of universities provides the data for this index. Three subindices comprise this category—salary and wages, fringe benefits, and indirect costs.

Two sources are used to compute a wage and salary index for each institution: the *Report on Medical Faculty Salaries*, published by the American Association of Medical Colleges, and *Academe: The Annual Report on the Economic Status of the Profession*, published by the American Association of University Professors. Salaries for medical school

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[46] Ibid., p. 13. The proposed fiscal year 1992 budget calls for a 13-percent increase in "research management and support," which covers the costs of administering the National Institutes of Health extramural research programs, especially the expenses of peer review panels (that have become "more labor-intensive"). Reported in "Ways and Means," *The Chronicle of Higher Education*, vol. 37, No. 23, Feb. 20, 1991, p. A25.

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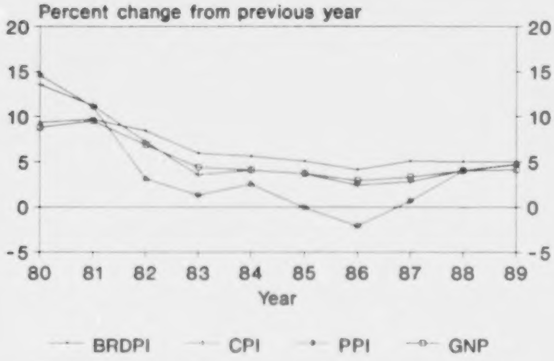
Figure 6-8—Comparison of BRDPI With Other Price Indices: Fiscal Years 1980-89



KEY: BRDPI=Biomedical Research and Development Price Index; CPI=Consumer Price Index; PPI=Producer Price Index; GNP=Gross National Product.

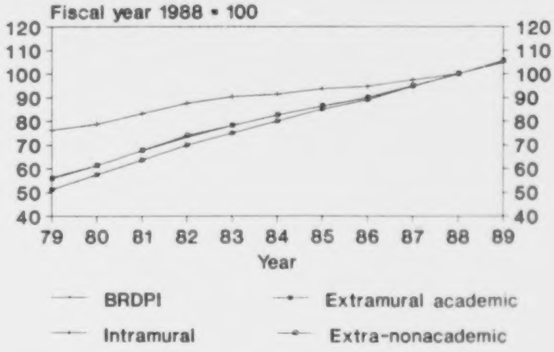
SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Biomedical Research and Development Price Index: Report to the National Institutes of Health* (Washington, DC: Mar. 30, 1990), chart 2.

faculty tend to be high and might have a disproportionate effect on salary calculations; biological scientists (not M.D.s) earn lower annual salaries (8 percent less) than scientists employed in most other fields.[47]

Indirect costs are calculated as a rate applied to direct costs. The "quantity" of indirect costs, therefore, is virtually impossible to define. According to the Department of Commerce, if indirect costs increase as a result of additional R&D, the increase is not a price change. If no additional R&D is performed, an increase in indirect costs is a price change. The criterion used to evaluate a change in the composition of indirect costs is whether or not the change has an impact on the performance of R&D. For example, if a university purchases a more powerful central computer and the indirect costs rate rises because that purchase is allowable as an indirect cost, the performance of R&D is probably enhanced. OTA finds this exception to indirect cost increases problematic, since it is not well defined and enhancement of the performance of research is not considered in other categories of expenditure.

For calculation of the indirect cost index in the BRDPI, an indirect cost rate index and a direct cost index are computed. These two indices are then multiplied together. The calculation of the BRDPI is conducted every year with the base year scheduled to be reset in 1992.

Figure 6-9—NIH Biomedical Research and Development Price Index: Fiscal Years 1979-89



KEY: NIH=National Institutes of Health.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Biomedical Research and Development Price Index: Report to the National Institutes of Health* (Washington, DC: Mar. 30, 1990), chart 1.

Research Expenditures at the National Science Foundation

Data are available on research expenditures funded by NSF up to fiscal year 1989. Expenditures are reported for the conduct of research, which includes basic, applied, and development; for R&D facilities, which include land, buildings, and fixed equipment; and for major equipment. The portion of the R&D budget allocated to facilities has been at less than 1 percent for the past 10 years, until the addition of a facilities funding initiative in 1988. Direct costs are available for personnel, R&D facilities, equipment, and instrumentation. Other direct costs are reported in the aggregate, but include supplies, publications, consultants, computer services, subcontracts, travel, and fringe benefits. This category accounts for over 27 percent of the budget.

At NSF, equipment has risen from 9 percent of the R&D budget in 1981 to over 13 percent in 1989. Personnel has accounted for about 40 percent of the R&D budget over the last decade. Indirect costs have

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[47] The number of institutions used to create the academic salary and wage price index represents 96 percent of total obligations. Each institution's separate salary and wage index is multiplied by its weight of obligations derived from the National Institutes of Health (NIH) IMPAC file, which contains data on all NIH awards for direct and indirect costs. These weighted data are summed to create the Academic Salary and Wage Price Index. The source used to create the fringe benefit index is *Academe*. Again, a fringe benefit rate index is created for each research institution. See National Science Foundation, *Profiles—Biological Sciences: Human Resources and Funding* (Washington, DC: 1989), p. 9.

Table 6-4—Biomedical Research and Development Price Index: Fiscal Years 1979-89 (1988 = 100)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
All performers	56.5	61.8	67.8	73.6	78.0	82.5	86.7	90.3	95.2	100.0	105.2
Intramural activities	76.3	79.0	83.3	87.7	90.4	91.7	93.6	94.4	97.6	100.0	104.3
Personnel	66.4	71.0	76.9	82.1	86.4	89.3	92.6	93.5	97.7	100.0	104.6
Nonpersonnel	84.6	85.7	88.7	92.5	93.8	93.8	94.5	95.2	97.5	100.0	104.1
Research function	76.7	79.9	84.6	89.0	91.4	92.7	94.2	94.8	97.7	100.0	104.5
Support function	75.5	77.0	80.5	85.1	88.2	89.7	92.3	93.7	97.3	100.0	103.9
Extramural activities	52.4	58.2	64.6	70.7	75.4	80.6	85.3	89.5	94.7	100.0	105.4
Academic grants and contracts	51.5	57.4	63.7	69.8	74.7	80.1	85.0	89.3	94.7	100.0	105.5
Personnel	52.4	57.0	62.7	69.1	73.7	78.3	84.1	88.7	94.1	100.0	105.0
Nonpersonnel	62.3	71.2	79.3	83.6	86.2	89.0	90.2	92.2	96.1	100.0	106.2
Indirect costs	44.3	50.5	56.8	63.5	70.3	78.2	83.6	88.7	94.9	100.0	106.0
Nonacademic grants and contracts	55.7	61.5	68.2	74.3	78.2	82.5	86.6	90.5	64.9	100.0	105.2

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Biomedical Research and Development Price Index: Report to the National Institutes of Health* (Washington, DC: Mar. 30, 1990), table 1.

Table 6-5—Biomedical Research and Development Price Index: Percent Change From Prior Fiscal Year, Fiscal Years 1980-89

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
All performers	9.4	9.7	8.6	6.0	5.8	5.1	4.2	5.4	5.0	5.2
Intramural activities	3.5	5.4	5.3	3.1	1.4	2.1	0.9	3.4	2.5	4.3
Personnel	6.9	8.3	6.8	5.2	3.4	3.7	1.0	4.5	2.4	4.6
Nonpersonnel	1.3	3.5	4.3	1.4	0.0	0.7	0.7	2.4	2.6	4.1
Research function	4.2	5.9	5.2	2.7	1.4	1.6	0.6	3.1	2.4	4.5
Support function	2.0	4.5	5.7	3.6	1.7	2.9	1.5	3.8	2.8	3.9
Extramural activities	11.1	11.0	9.4	6.6	6.9	5.8	4.9	5.8	5.6	5.4
Academic grants and contracts	11.5	11.0	9.6	7.0	7.2	6.1	5.1	6.0	5.6	5.5
Personnel	8.8	10.0	10.2	6.7	6.2	7.4	5.5	6.1	6.3	5.0
Nonpersonnel	14.3	11.4	5.4	3.1	3.2	1.3	2.2	4.2	4.1	6.2
Indirect costs	14.1	12.6	11.6	10.7	11.3	6.8	6.1	7.0	5.4	6.0
Nonacademic grants and contracts	10.4	10.9	8.9	5.2	5.5	5.0	4.5	4.9	5.4	5.2

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Biomedical Research and Development Price Index: Report to the National Institutes of Health* (Washington, DC: Mar. 30, 1990), table 2.

fluctuated around 25 percent over the past 10 years.[48] The Academic Research Facilities Modernization program, authorized in 1988 as part of NSF's 5-year reauthorization, committed up to $80 million in fiscal year 1989, but no funds were appropriated for it in that year. Funds were finally obligated on September 1, 1990.[49]

Trend data on research expenditures administered by NSF are spotty. Expenditure data are readily available but do not provide a sense of actual costs incurred (or shared) by the researcher. While NSF routinely collects aggregate data on R&D spending and expenditures across the Federal agencies, its own databases are not nearly as comprehensive as those kept by NIH.

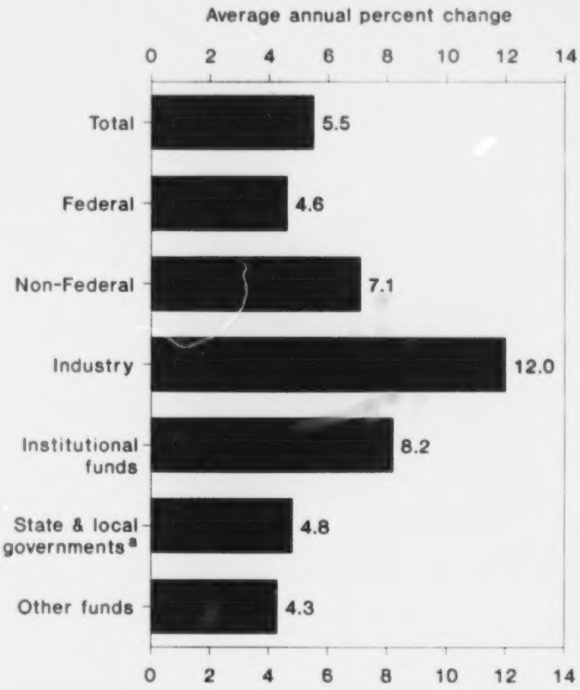
The Research Performer's Perspective on Expenditures

The definition of "research performer" has many components. The most obvious is the researcher or team in a university, industrial facility, or Federal laboratory. Another level is the department or other organizational unit within a university or laboratory. At the most aggregated level are the laboratories and universities themselves. Given the concentration of research performance in universities, most expenditure data are based on this sector.

The Federal Government supplied $9.2 billion in research funds to universities in 1990. Industry supplied $1.1 billion and another $1.1 billion came from nonprofit institutions. Between 1978 and 1988, the average annual growth above inflation was 5.5 percent (see figure 6-10). Industry has provided most of the increase in funds, since growth of industrial funding for university R&D averaged 12 percent above inflation per year during that time period. Funding from nonprofit institutions increased annually by an average of 8.2 percent in real terms over that period, and the Federal Government increased its support of university R&D by an annual average of 4.6 percent above inflation. (Figure 6-11 presents Federal *basic* research by performer.)

Since the 1960s, the Federal research system has changed in many ways, not the least of which is in the nature of the research performer. For instance, during the 1960s, a professor with two to six students in one discipline at a major research university was the most prevalent production unit of research. In the 1990s, many other types of research units exist, in particular much larger research groups with many graduate students, nontenure track researchers, postdoctoral fellows, and technicians under one principal investigator. The rise of centers and university research institutes now augments the traditional array of disciplinary "departments" (see chapter 7).

Figure 6-10—Growth in University and College R&D Performance, by Source of Funds: Fiscal Years 1978-88 (based on constant dollars)



[a]Excludes general-purpose State or local government appropriations that universities use at their discretion for R&D.

NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator.

SOURCE: National Science Foundation, *National Patterns of R&D Resources: 1990*, final report, NSF 90-316 (Washington DC: 1990), chart 13.

Similarly, the number of universities and Federal laboratories that conduct research has grown, expanding the group of researchers that pursue specialized forms of inquiry in the research system. These changes have occurred primarily to accommodate

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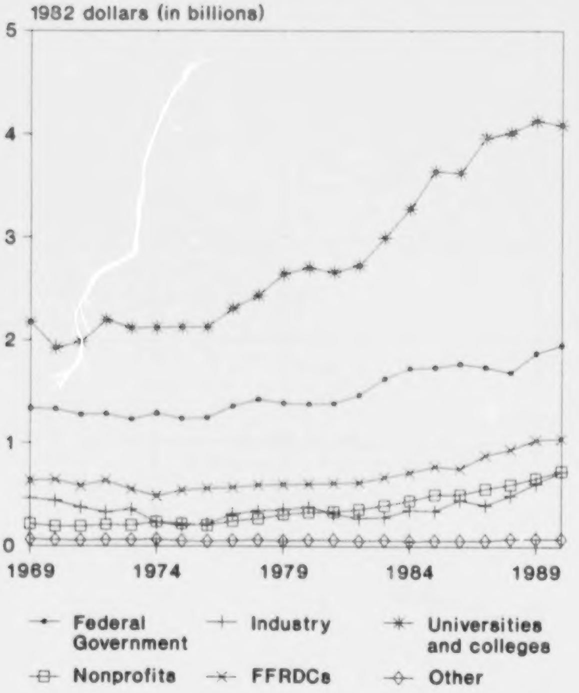
[48] National Science Foundation budget office, personal communication, July-August 1990.

[49] In January 1991, the National Science Foundation announced the 78 research institutions awarded a total of $39 million under this program. See Constance Holden, "Facilities Awards," *Science*, vol. 251, Feb. 8, 1991, p. 622.

Figure 6-11—Federally Funded Basic Research, by Performer: Fiscal Years 1969-90
(in billions of 1982 dollars)



KEY: FFRDCs include all Federally Funded Research and Development Centers that are *not* administered by the Federal Government. Other includes Federal funds distributed to State and local governments and foreign performers.

NOTE: Figures were converted to constant 1982 dollars using the GNP Implicit Price Deflator. 1990 figures are estimates.

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table 27; and National Science Foundation, *Selected Data on Federal Funds for Research and Development: Fiscal Years 1989, 1990 and 1991* (Washington, DC: December 1990), table 1.

growth in the system.[50] The annual rate of growth for doctoral scientists and engineers employed in institutions of higher education from 1977 to 1987 was just under 3 percent.[51] Some universities are feeling the strain felt by the scientific community, claiming that capital needed to fund renovations and new construction, equipment, administration, and personnel are rarely fully recovered through Federal funds.

Components of Research Expenditures at Universities

To document the effect of the research economy on changing university and laboratory structures, and to complement the Federal perspective presented above, OTA visited a public and a private research university—the University of Michigan (UofM) and Stanford University (SU) (see box 6-B). In addition, OTA visited at least one laboratory for each of the five major research agencies with intramural laboratories. However, expenditure data are scarce at the Federal laboratories and not uniformly collected. This section, therefore, discusses the performer's perspective on expenditures (with details derived from the two universities), and then outlines other issues that also influence spending in the conduct of research.

Both UofM and SU show evidence of robust research organizations, with excellent human resources, facilities, and financial support. This is as it should be in a top-ranked university with a long history of success (see box 6-C). Nevertheless, there was evidence of stress in the research environment at both institutions, although it was unclear whether this was a new phenomenon. Researchers said they were "running harder just to stay in place." University administrators wondered whether their institution could continue to expect resources to flow from the Federal Government, student tuition, and State and private sources.[52] Graduate students worried about whether their careers could ever be like those of their mentors.

Salaries

University personnel spoke of the rising competition for faculty with other sectors of the economy, and noted that faculty salaries have been rising significantly over inflation during the last decade. In 1988 dollars, the average salary and benefits for a full-time equivalent principal investigator in the natural sciences and engineering increased from $59,000 in 1981 to $70,000 in 1988. Before the 1980s, growth occurred much more slowly from $51,000 in 1958 (1988 dollars) to over $60,000 in

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[50] See Roger L. Geiger, "The American University and Research," *The Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives*, Government-University-Industry Research Roundtable (ed.) (Washington, DC: National Academy Press, 1990), pp. 15-35.

[51] National Science Foundation, *Science and Engineering Personnel: A National Overview*, special report (Washington, DC: 1990).

[52] Also see Susan Tifft, "Hard Times on the Old Quad," *Time*, Oct. 29, 1990, p. 92.

Box 6-B—OTA Interviews at Two Universities

To explore performer perspectives on research expenditures and on Federal research initiatives, OTA chose one public and one private research university for indepth study: the University of Michigan and Stanford University. OTA purposely selected two research institutions perennially in the top 10 of those receiving Federal research dollars, because of the breadth of research performed on campus. Also, the problems found at these universities in setting expenditures and expanding flexibility are thought to be indicative of problems on other research-intensive campuses.

In addition to receiving financial and personnel data from each university, OTA interviewed members of the administration, faculty, and graduate student population on campus. The interviews centered on two themes: 1) research expenditures, and 2) flexibility of the university and its departments to adapt to the changing Federal funding environment. Other issues discussed included the status of nontenure track faculty, hiring projections for individual departments, tenure promotion standards, and the graduate student perspective on careers in different fields.

The interviews sampled the range of personnel on campus. For example, at Stanford, OTA interviewed the president (Donald Kennedy), the dean and associate dean of research, two department chairs, three professors, three associate professors, one research associate (nontenure track), one postdoctoral fellow, two graduate students, the director and other members of the Sponsored Projects Office, the assistant controller, specialists in the Office of the Budget and the Office of Technology Licensing, and the director of the Stanford Synchrotron Radiation Laboratory. The interviewees were selected from a number of disciplines, including the physical sciences, engineering, medicine, and the social sciences. At Michigan, a similar set of interviews was conducted.

OTA summarized the findings at each university and distributed the summaries to the campus hosts for comment. Select findings are used throughout this report, especially in this chapter.

SOURCE: OTA interviews, July-August 1990.

the early 1970s, but salaries receded slightly in the late 1970s to $59,000 in 1981[53] (see figure 6-12).

Universities are encouraged by faculty attempts to leverage their time with the help of postdoctoral fellows, nontenure track researchers, and graduate students who are paid modest salaries. Because of the shortage of faculty positions for the numbers of graduate students produced, young Ph.D.s have been willing to take these positions in order to remain active researchers. This availability of "cheap labor" is seen by many senior researchers as the only way they can make ends meet in competing for grants.[54]

Academic Facilities

Academic administrators claim that with growing frequency aging utility systems in laboratories and classroom buildings falter and break down.[55] A 1989 Coopers and Lybrand study found that:

- Since 1950, the facility space in colleges and universities has quintupled, representing some 3 billion square feet of classrooms, libraries, dormitories, offices, laboratories, and other space. Not all of this space was built to last. In particular, during the 1960s, many suboptimal buildings were erected, in the rush to meet the demand from the "baby boom" generation entering college.
- The capital renewal and replacement needs of U.S. colleges and universities are roughly $60 billion, of which slightly over $20 billion is "urgent"—requiring attention within the next several years. Only $7.2 billion of the urgent category was targeted to repair facilities in the

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[53] See Government-University-Industry Research Roundtable, op. cit., footnote 17, p. 2-34.

[54] Labor economist Alan Fechter (executive director, Office of Scientific and Engineering Personnel, National Research Council, personal communication, Nov. 15, 1990) writes: "... personnel costs constitute roughly 45 percent of total costs and ... this percentage has remained reasonably stable over time. Given that salaries of faculty (i.e., principal investigators) have been rising during the 1980s, this suggests that the staffing pattern of research projects has been changing, with the input of PIs decreasing relative to ... other, less expensive resources. There is some evidence to support this hypothesis in the report of GUIRR ... [that] finds in academia an increasing ratio of nonfaculty to faculty." See also ibid.

[55] Karen Grassmuck, "Colleges Scramble for Money to Reduce Huge Maintenance Backlog, Estimated to Exceed $70 Billion; New Federal Help Seen Unlikely," *The Chronicle of Higher Education*, vol. 37, Oct. 10, 1990, pp. A1, A34.

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Box 6-C—Federal Funding at Two Universities

The University of Michigan (UofM) and Stanford University are in the top 10 universities receiving Federal funds. UofM was ranked fifth and Stanford was second in fiscal year 1988. Over the past decade, both universities have been the recipients of large (real) increases in total funds and Federal research dollars. For example, in constant (1980) dollars, UofM total revenues have risen from $600 million in 1979-80 to nearly $1 billion in 1988-89 ($1.5 billion in current dollars).

From 1979 to 1989, Federal research funds for UofM rose from $117 million (17 percent of total revenues) to $188 million (13 percent of total revenues) in constant 1986 dollars. In the period from 1976 to 1986 at Stanford, the total Federal R&D obligations to the university rose from $122 million to $194 million (1986 constant dollars). In addition, from 1973 to 1986, the funds available to principal investigators (PIs) to spend directly on research activities grew after inflation at an average annual rate of 2.6 percent.

The Department of Health and Human Services (HHS) is the largest Federal funder of research and development (R&D) at both universities ($124 million at UofM and $170 million at Stanford in fiscal year 1989). At UofM, HHS is followed by the National Science Foundation (NSF—$24 million), the National Aeronautics and Space Administration (NASA—$13 million), the Department of Defense (DOD—$10 million), and the Department of Energy (DOE—$9 million) in fiscal year 1989. At Stanford, after HHS comes NASA ($50 million), DOD ($45 million), DOE ($45 million), NSF ($30 million), and the Department of Education (ED—$10 million) in fiscal year 1989. From 1973 to 1985, Stanford's share of total Federal R&D funding (across all agencies) has remained around 2.7 percent.

Proposal Success Rates

Stanford and UofM, like most top 10 universities, have a higher proportion of awards per proposals submitted than the average for other research universities. For instance, although UofM does not track its proposals directly, it estimates that two out of three proposals were awarded funds. At roughly two-thirds, its "proposal success rate" is at least twice the national average of 20 to 35 percent for all proposals (with the exact percentage dependent on the agency).

Roughly the same proposal success rate is found at Stanford, although they distinguish between "new proposals" and "renewals." For new proposals in 1989-90 (453 proposals sampled), DOD funded 35 percent; NSF, 36 percent; ED, 37 percent; DOE, 41 percent; HHS, 52 percent; NASA, 52 percent; and 57 percent averaged for all other agencies. Renewals had much higher success rates (470 proposals sampled): HHS funded 67 percent; DOD, 75 percent; NASA, 80 percent; DOE, 81 percent; NSF, 81 percent; ED, 100 percent; and 66 percent averaged for all other agencies.

Indirect Costs

At UofM, growth in the indirect cost expenditures for the university as a whole grew at an annual compound rate of 10.3 percent from 1979-80 to 1988-89. However, indirect costs for organized research did not rise as quickly—at a compound rate of 9.1 percent from 1980-81 to 1988-89. Although the cost of maintaining buildings, equipment, and plant operation for organized research were higher than for other buildings at the university, student services, libraries, and sponsored project research expenditures were lower.

In the early 1980s, the UofM negotiated indirect cost rate (ICR) for research underestimated the "true" rate by as much as 20 points in 1 year (1984-85). (Note that the cognizant agency for UofM is HHS, which traditionally allows lower ICRs than DOD.) At present, the negotiated rate of 58 percent only slightly underestimates the "true" rate of 60 percent, even though a 58 percent ICR is the highest of *all* public universities.

Stanford's ICR was raised from 69 percent to 74 percent in 1987. However, this rate is currently under investigation by the Office of Naval Research (ONR) and the House Committee on Energy and Commerce.[1] Although Stanford's ICR is high, it is comparable to rates from other private research institutions, including Cornell University which has an ICR of 74 percent and Yale with an ICR of 72 percent.

In response to complaints about the high ICR and the rising tuition, expenditures incurred by the 1989 Loma Prieta earthquake, and the lower than anticipated federally sponsored research, Stanford has embarked on a cost-cutting campaign. It will cut $22 million over 18 months out of a $175 million administrative operating budget.

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[1] See Marcia Barinaga, "Stanford Sails Into a Storm," *Science*, vol. 250, Dec. 21, 1990, p. 1651; "Government Inquiry," *Stanford Observer*, November-December 1990, pp. 1, 13; and Marcia Barinaga, "John Dingell Takes on Stanford," *Science*, vol. 251, Feb. 15, 1991, pp. 734-737.

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Salaries

Salaries at both UofM and Stanford have risen above inflation over the past two decades (exact figures were not made available to OTA). Both institutions state that higher salaries are required to attract faculty. Experiments with congressionally imposed (now rescinded) salary caps at NSF and the National Institutes of Health, which provided upper limits on annual investigator salary rates charged to research grants (even though only a few months of support may be sought in the grant), affected both universities. (Note that faculty were not required to reduce their salaries as the university made up the difference.) For example, if every faculty member at UofM had an NSF grant, then one-quarter of the faculty would have been affected by the $95,000 salary cap.

Facilities

Over the last 15 years, UofM has completed nearly $1 billion in new construction and major renovation. The amount of building space on campus totals over 22 million square feet. Many of the structures date to before 1950, and no building is "temporary." Also, the university has demolished very few permanent, older buildings. Since the 1960s, Federal and State funds have been limited for facilities, and expansion has occurred slowly at UofM compared with other universities around the country.[2] Recently the university has been outfitting buildings with energy-efficient equipment, such as new thermal windows. Also, environmental regulations have required some improvements. For instance, a large effort to install or replace fume hoods is under way.

At Stanford, an ambitious new construction project—the Near West Campus—has begun. There are plans for at least five new buildings, providing primarily state-of-the-art laboratory and office space. Most of the funds for construction are from private sources, but if measures are not taken (such as a successful cost-cutting campaign, or an adjustment of the ICR by ONR), Stanford's indirect cost rate could rise to account for the depreciation of the new buildings.

Both Stanford and UofM question their abilities to meet their perceived need for new and renovated buildings. Each would like to see an expanded Federal facilities program for academic research.

Projections for Future Federal Support

UofM and Stanford project an overall slowing of growth in Federal R&D support. Whereas both universities had come to expect a 10 to 15 percent increase per year during most of the 1980s, the increase in Federal funds at Stanford in 1989, for example, was 9 percent. University personnel forecast that similar limited growth will continue into the 1990s. Adjustments will have to be made on both campuses to accommodate slowed growth in Federal funding.

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[2] Note that the university system in Michigan expanded to other campuses in Michigan during the college boom in the 1960s and 1970s. Most of these satellite campuses have since closed.

> Nation's major research universities. Most of these needs, therefore, exist within other academic sectors, including liberal arts and community colleges.[56]

Many claim that facility reinvestment has not kept pace with growing needs, and Coopers and Lybrand estimate that for every dollar spent on maintenance and replacement, $4 are deferred. They further estimate that current costs to replace a laboratory are roughly $200 per square foot, while classrooms require less than $100 per square foot.

However, the picture is not as clear as the above data would suggest. When asked by NSF if their facilities are poor, fair, good, or excellent, a majority of the research administrators and deans at the top 50 research universities replied that their facilities were "good to excellent," whereas a majority of the research administrators and deans in the schools below the top 50 estimated that their facilities were "fair to poor." The average top 50 university will spend $1 to $2 million or more on facilities each year, while the schools below the top 50 will most often spend less than $1 million. For public universities, 50 to 60 percent of these funds come from the

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[56] *The Decaying American Campus: A Ticking Time Bomb* is a joint report of the Association of Physical Plant Administrators (APPA) of Universities and Colleges and the National Association of College and University Business Officers in cooperation with Coopers and Lybrand, authored by Sean C. Rush and Sandra L. Johnson, APPA (Alexandria, VA, 1989). APPA's most recent "deferred maintenance" cost estimate is $70 billion. Also in 1990, 42 percent of college and university presidents surveyed by the American Council on Education called deferred maintenance a key campus issue for the next 5 years, up from 14 percent in 1989. See ibid., p. A34.

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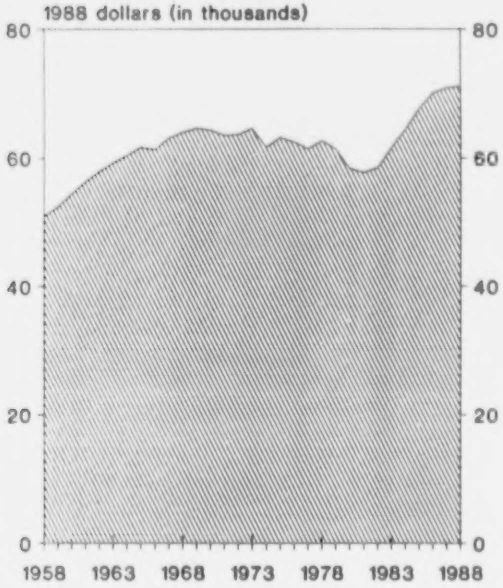
Figure 6-12—Average Salary and Benefits Paid Academic Ph.D.s in Natural Sciences and Engineering: 1958-88
(In thousands of 1988 dollars)



NOTE: Constant dollars were calculated using the GNP Implicit Price Deflator.

DEFINITION OF TERMS: Academic Ph.D.s in the natural sciences and engineering include academic employees who have been awarded the Ph.D. degree in the following fields: life sciences, including agricultural, biological, medical, and other health sciences; physical sciences, including astronomy, chemistry, and physics; engineering, including aeronautical and astronautical, chemical, civil, electrical, and mechanical engineering; environmental sciences, including oceanography, and atmospheric and earth sciences; and mathematics and computer science, including all fields of mathematics and computer-related sciences. Compensation includes salaries and fringe benefits, including insurance and retirement contributions.

DATA: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data in this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges; National Institutes of Health; American Association of University Professors; National Association of State Universities and Land-Grant Colleges.

SOURCE: Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues* (Washington, DC: National Academy Press, 1989), figure 2-47.

Photo credit: Stanford University

Research universities support many facilities devoted in part to research, such as the Seeley C. Mudd Chemistry Building at Stanford University pictured here.

States and 30 percent from bond issues. For private universities, roughly one-third comes from the Federal Government, while another one-third is from donations.[57]

The crux of the facilities problem is that academic centers can always use new or augmented buildings, but how much is enough? One method to judge would be based on the research fostered by each new facility. Unfortunately, there is no acceptable method to measure the quality or quantity of increased research capabilities or of "missed" research opportunities. Even though "need" may not be quantified in the different sectors of the research enterprise, a demand certainly exists. For example, when NSF solicited proposals for a $20 million program in 1989 to address facilities needs, it received over 400 proposals totaling $300 million in requests.[58]

Historically, the Federal Government has never been the primary source of funding for academic facilities, conceding support to private donors, States, and localities. Indeed, the proportion of Federal monies out of all the monies spent on academic facilities has never topped one-third. Now it is less than 10 percent.[59]

The issues surrounding the research infrastructure are complicated. There is a need for improvement—as evidenced in many research environments—but the need is very hard to quantify or assess. In addition, the extent of the Federal role—should there be a Federal facilities program?—is in question. Do deteriorating facilities affect the quality of research underwritten by the Federal Government? Academic earmarks for facilities continue to play an ad hoc role that unfortunately fails to address the facilities renovation issue directly or systematically (as a formal Federal facilities program perhaps would, see box 6-D).

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[57] Michael Davey, *Bricks and Mortar: A Summary and Analysis of Proposals to Meet Research Facilities Needs on College Campuses* (Washington, DC: Congressional Research Service, 1987).

[58] The National Science Foundation program also requires a 50-50 match for requests ranging from $100,000 to $7 million. Some, including the President's Science Advisor, estimate the price of academic facilities modernization to be $7 billion. See Jeffrey Mervis, "Institutions Respond in Large Numbers to Tiny Facilities Program at NIH, NSF," *The Scientist*, vol. 4, No. 8, Apr. 16, 1990, p. 2.

[59] Davey, op. cit., footnote 57.

Indirect Costs

One of the most worrisome issues on many research campuses is the high cost of "overhead" or indirect costs. As part of the "full cost recovery for research" doctrine in the Federal Government, universities charge the Federal Government for facilities maintenance, administrative expenses, and other expenditures that ensure their capacity as research performers but cannot be directly associated with specific projects. The standard procedure is for the university to negotiate a single rate that will be charged to all Federal grants with the cognizant Federal agency (either the contract audit agency of the Department of Defense or the Department of Health and Human Services, depending on the institution).[60] For example, in 1990, Stanford University charged 74 percent in indirect costs to every grant, so a grant of $100,000 in direct costs might be submitted at a total cost of up to $174,000.[61] (Overhead can be computed on only certain direct costs, resulting in a total charge to the government of less than $174,000.) Indirect cost rates have evolved over the last 30 to 40 years, and clearly reflect institutional idiosyncrasies and practices of the cognizant agency.

Over the past three decades, indirect costs have claimed a much larger proportion of academic R&D funding. In 1958, federally reimbursed indirect costs comprised 10 to 15 percent of academic R&D funding. By 1988, that share had risen to roughly 25 percent.[62] In addition, some agencies allow more in indirect costs. For example, in 1988, the indirect cost as a percent of the total R&D expenditures at NIH was 30 percent, whereas it was less than 24 percent for NSF (a proportion unchanged since the mid-1980s).[63] Medical schools typically have high indirect cost rates, both because of the extra facilities expenditures associated with their activities and because they tend to be associated with the research universities that have high indirect cost rates.[64]

The indirect cost rate at the University of Michigan is 58 percent, which is high for a public university. Because the State assumes part of the cost of maintaining its universities, the indirect cost rates are usually lower than at private universities. In addition, at State universities, indirect cost monies are often transferred directly to State coffers, so that the university has little incentive to pursue a higher indirect cost rate or to employ the administrative personnel needed to comply with Federal audit requests to justify new rates.

Many university administrators report that the monies received in indirect costs do not cover their expenditures. They worry about further erosion of the indirect cost base, due to the perception in many quarters of high rates of overhead and resistance to the indirect cost increases experienced by many universities over the last decade.[65] The chief recommendation offered by a 1988 Association of American Universities report was that the indirect cost rate

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[60] Association of American Universities, op. cit., footnote 14, p. 7.

[61] As a result of the Defense Contractor's Audit Agency's (DCAA) ongoing investigation of Stanford's indirect cost rate, an interim rate of 70 percent has been negotiated as of Feb. 1, 1991. William Massy, Stanford University, personal communication, February 1991. DCAA's preliminary analysis indicates that Stanford, which requested a new indirect cost rate of 78 percent, could justify only a 62 percent rate. Stanford has yet to rebut this claim. See Marcia Barinaga, "Was Paul Biddle Too Tough on Stanford?" *Science*, vol. 251, Jan. 11, 1991, p. 157; Kenneth J. Cooper, "Stanford Will Try to Explain Price of Knowledge," *The Washington Post*, Mar. 13, 1991, p. A15; and Kenneth J. Cooper, "Panel Looks for Liability in Stanford Billings Case," *The Washington Post*, Mar. 15, 1991, p. A21.

[62] National Science Foundation, op. cit., footnote 19, p. 121.

[63] Ibid., p. 142; and Association of American Universities, op. cit., footnote 14. For example, restricting payment for overhead expenses to 14 percent on research projects funded by the Department of Agriculture has aroused concern that universities would have to decline such awards since they could not afford to do the projects. Fears that such an across-the-board ceiling could be instituted at other agencies continue to mount. See Colleen Cordes, "Universities Fear That U.S. Will Limit Payments for Overhead Costs Incurred by Researchers," *The Chronicle of Higher Education*, vol. 37, No. 12, Nov. 21, 1990, pp. A19, A21.

[64] William Massy, vice president for finance, Stanford University, personal communication, March 1991.

[65] "Dingell Asks Defense Contract Audit Agency to Brief Staff on Stanford Overhead Expenses," *Washington Fax*, Dec. 10, 1990. Also, see Susan Tifft, "Scandal in the Laboratories," *Time*, Mar. 18, 1991, pp. 74-75; and Kenneth J. Cooper, "Five Major Universities Face GAO Audit of Research Bills," *The Washington Post*, Mar. 16, 1991, p. A2.

Box 6-D—A Federal Research Facilities Program? Perspectives From Academia

In August 1990, University of Wisconsin at Madison Chancellor Donna E. Shalala wrote to President Bush urging development of a comprehensive plan to finance university research facilities. She stated:

> I recognize that there are a number of important competing claims on the Federal budget, even from the academic community. However, a planned Federal strategy at this stage can well save us money in the long run, and make more effective our other investments in science and engineering research and training.[1]

Even if money were appropriated to a Federal facilities program, there would be tough choices, such as an equal distribution of funds by category of institution or some weighted scheme that favors research-intensive universities.[2] Stanford's former Vice President for Finance, William E. Massy, outlines the following possible pitfalls:[3]

> What would happen if research sponsors were to shoulder the load of paying for needed university science facilities? . . . Research sponsors might adopt the "pay-now" strategy and provide the needed $5.85 billion up front. Congress is considering a facilities grant program, but it is hard to believe that anything like this amount could be provided over a few years without huge inroads on operating funds for research.
>
> On the other hand, if the "pay-later" strategy were adopted by sponsors, institutions would have to come up with up-front money on their own and then try to recover it through the overhead rate. This could be done in one of two ways: 1. Use gifts, institutional funds, or State appropriations. . . .[4] 2. Use debt. . . .
>
> Providing direct grants for facilities is an attractive option on its face, but . . . amounts would probably be modest in relation to need because of the [Federal] deficit. There is a real danger that appropriations would be at the expense of operating funds for science. . . . One reason for favoring a grant program is that it makes facilities available to institutions that are unable to provide up-front funding. . . . But it is precisely the institutions that have not yet been successful in merit-reviewed scientific competition that have the most need for a facilities grant program and would benefit most from it. . . .
>
> Facilities funding on a "pay-as-you-go" basis through the indirect cost rates puts the burden . . . on the institutions, and then reimburses them for some or all of the present value of these outlays. . . . Indirect cost rates would rise, . . . [and] institutions would have to bear the risks that a facility, once constructed, could not be filled with sponsored research at full overhead recovery. (The Federal Government takes that risk in an up-front grant program.) . . .
>
> While the Federal Government would be unlikely to announce a "won't pay" policy, that could happen by default if deficit reduction, "no new taxes," social programs, and defense come to dominate the need for university science facilities. A "won't pay" policy would preclude facilities grants, and it might also open the way for caps on indirect cost rates and elimination of universities' tax benefits . . .

When the scope of a problem is unknown, as with the need for academic research facilities, questions of which is the most appropriate policy is even harder to answer. To this end, a six-university consortium, called the Center for Policy Research and Education, has been established to study university finance and cost containment, investigating ". . . growth by substitution rather than by adding on cost."[5] In the meantime, neither universities nor the Federal Government face the prospect of easy solutions.

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[1] Quoted in Karen Grassmuck, "Colleges Scramble for Money to Reduce Huge Maintenance Backlog, Estimated to Exceed $70 Billion; New Federal Help Seen Unlikely," *The Chronicle of Higher Education*, vol. 37, No. 6, Oct. 10, 1990, p. A34.

[2] Other administrative questions include: a single program or a line item in the budget of each research agency, a separate amount for repair and renovation v. new construction, and an institutional matching requirement. For further discussion, see Government-University-Industry Research Roundtable, "Research Facility Financing: Near-Term Options," working draft, February 1991.

[3] Drawn from William E. Massy, "Capital Investment for the Future of Biomedical Research: A University Chief Financial Officer's View," *Academic Medicine*, vol. 64, 1989, pp. 435-437. The dollar estimates for construction he cites are drawn from National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1988* (Washington, DC: 1989).

[4] On the cost-efficiency of academic fundraising, see Liz McMillen, "A Study to Determine the Cost of Raising a Dollar Finds That Average College Spends Just 16 Cents," *The Chronicle of Higher Education*, vol. 37, No. 1, Sept. 5, 1990, pp. A31-32.

[5] See "Education Finance," *Stanford Observer*, November-December 1990, p. 14. The Department of Education's Office of Educational Research and Improvement is funding the consortium consisting of the University of Southern California, Rutgers-The State University of New Jersey, Harvard University, Michigan State University, the University of Wisconsin at Madison, and Stanford University. The Stanford component, at the Institute for Higher Education Research, will be headed by William Massy.

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should be split into two rates—one for facilities and equipment (including operation, maintenance, and depreciation) and a second for all other components (including administration, library, and student services).[66] The academic research community is also hoping that OMB will reconsider Circular A-21, which deals with indirect cost practices.[67]

High indirect cost rates are often seen as detrimental to the researcher, because they increase the total expenditures for research grants while adding no additional money for research. For example, many Stanford University faculty are so concerned about a proposed increase in the indirect cost rate that they have pressured the university to cut administrative and facilities expenditures.[68]

Does the overhead rate reflect true differences related to the instructional capacity at universities or is it due to some accounting mechanism? Before new policies are crafted, data on actual expenditures should be collected and presented so they are amenable to comparisons across institutions. In the process, both universities and the Federal Government have much to gain in making the system more simple, transparent, and credible.

Changing Expectations and Competition

Research expenditures increase for reasons besides the line item components of a budget. Researchers also point to higher expectations for their research, which require more spending and competition in the university environment.

Academic researchers, both young and old, are asked today to publish more papers, shepherd more graduate students, and bring in more Federal funding than their predecessors.[69] To boost research productivity, faculty members hire postdoctorates and nontenure track (nonfaculty) researchers. Graduate students can—and do—take over portions of faculty teaching responsibility; technicians and graduate students can maintain equipment and run experiments; and postdoctorates and nonfaculty researchers can advise students and assist in the operation of the laboratory.[70] All can perform research.

Photo credit: University of Michigan

The calculation of indirect costs is often difficult because of inherent problems with separating instruction from research activities on a university campus.

For example, in the chemistry departments of both UofM and SU, the average number of graduate students per faculty averages about six to nine. Some professors have as many as 25 to 30. Much chemistry research involves long hours in laboratories, so the pace of research is brisk as well as necessitating the participation of a greater number of graduate students. Once a faculty member in a department or related field succeeds in expanding his or her research group, others also expand their groups to keep pace.[71]

In this very competitive research system there is increasing pressure to perform more research and to publish more papers. Consequently, expectations and expenditures have risen. Perhaps one young faculty member at Stanford put it best:

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[66] Association of American Universities, op. cit., footnote 14.

[67] See "OMB Unlikely To Open Circular A-21 for Amendment According to Indirect Cost Observers," *Washington Fax*, Dec. 12, 1990; "AAU Says Talks Continue at High Level in OMB To Reopen OMB Circular A-21," *Washington Fax*, Dec. 13, 1990; and Robert M. Rosenzweig, "The Debate Over Indirect Costs Raises Fundamental Policy Issues," *The Chronicle of Higher Education*, vol. 37, Mar. 6, 1991, p. A40.

[68] Faculty argue that Stanford's indirect cost rate detracts from the attractiveness of funding research at Stanford, i.e., they are at a competitive disadvantage. Eileen Walsh and Karen Bartholomew, "Indirect Costs Subject of Three Separate Reviews," *Campus Report*, Sept. 12, 1990, pp. 1, 6.

[69] This is especially true in entrepreneurial research areas such as biotechnology. See Henry Etzkowitz, "Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science," *Minerva*, vol. 21, Nos. 2-3, summer-autumn 1983, pp. 198-233.

[70] See Sidney Perkowitz, "Larger Machines Are Breeding Larger Research Teams," *The Scientist*, Oct. 16, 1989, pp. 13, 15.

[71] This trend emerged from OTA interviews at Stanford University and the University of Michigan, July-August 1990.

> Each year, we have to write more papers and bring in more money than many of the senior professors ever produced in *any* year of their careers. When we were hired as assistant professors, we already had to have published five or ten papers, again more than any of them had to do. And, it keeps getting worse.[72]

Whether the premium on productivity defined by number of papers published is attenuating their quality is unclear. Bibliometric data, which provide a measure of use through citations, indicate that about 15 percent of all U.S. scientific papers are never cited.[73] Publishing requires research; doing more research requires spending more money. Thus, research expenditures are not just a *cost* issue, but a *spending* issue as well.

Relative Deprivation

When there is such pressure to compete, standards become "whatever it takes to make it." Most professors understand how much money and how many graduate students they will need to help them produce enough papers to get tenure, promotions beyond tenure, and recognition in their field. Many hope to do more.

However, if they do not meet these expectations, some report a sense of failure.[74] Failing to meet self-imposed expectations only intensifies these feelings. This is true even if the economy of work has changed such that standards of productivity need to be revised, or if they have succeeded but not by as much or as quickly as they had hoped. Social scientists call this situation "relative deprivation." Researchers, especially on campuses such as the University of Michigan or Stanford University, cannot be said to be "absolutely" deprived. They are able to acquire laboratory space, graduate students, and research monies; they produce very significant amounts of research; and the success rates for proposals at UofM and SU run at least twice if not three times the national average (roughly two out of three proposals are awarded funds, averaged over these two universities).

Nevertheless, the professors at UofM and SU have grown accustomed over the last 20 years to producing more graduate students, more publications, and funding for perhaps four of every five proposals they submit.[75] The adjustment to comparatively less has been difficult. Relative deprivation is real, but so is the greater sophistication of instruments, complexity of experiments, and amount of research that can be completed in a short time. There is also a trend toward an "industrial model," where project teams are larger and responsibilities are more distinct within the group.[76] Research institutions are keyed to hastening and demonstrating research productivity.

Some experiments have been attempted on U.S. campuses to temper the drive for more research *output*. For example, at Harvard Medical School, faculty are allowed to list only five publications for consideration at tenure, with similar numbers set for other promotions. Thus, the quality and importance of the candidate's selected set of papers is stressed, though measuring these characteristics, bibliometrics notwithstanding, remains contentious.[77]

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[72] OTA interviews at Stanford University, August 1990.

[73] This was originally reported as nearly one-half going uncited. See David P. Hamilton, "Publishing By—and For?—the Numbers," *Science*, vol. 250, Dec. 7, 1990, pp. 1331-1332; and David P. Hamilton, "Research Papers: Who's Uncited Now?" *Science*, vol. 251, Jan. 4, 1991, p. 25. The data source, the Institute for Scientific Information, reports that the original estimate included notes, editorials, and meeting abstracts. When scientific articles alone are considered, uncitedness by 1988 of articles published in 1984 drops to 22 percent. For U.S. authors, the proportion is even lower (14.7 percent), one-half that for non-U.S. authors. See David A. Pendlebury, "Science, Citation, and Funding," letter, *Science*, vol. 251, Mar. 22, 1991, pp. 1410-1411. Journals, however, appear to have increasingly assumed a more archival function of bestowing credit than of information exchange. Citation rates, however, are known to vary widely by field. This may reflect more on the ways researchers *credit* one another through bibliographic references than on how they actually use that work. See Derek de Solla Price, "Citation Measures of Hard Science, Soft Science, Technology and Nonscience," *Communication Among Scientists and Engineers*, C. Nelson and D. Pollock (eds.) (Lexington, MA: D.C. Heath, 1970), pp. 3-22.

[74] *Science: The End of the Frontier*? op. cit., footnote 4.

[75] OTA interviews, op. cit., footnote 71.

[76] Elsewhere this has been called the "industrialization" of science, or ". . . a new *collectivized* form in which characteristics of both the academic and industrialized modes are intermingled." See John Ziman, *An Introduction to Science Studies* (Cambridge, England: Cambridge University Press, 1984), p. 132. The dimensions of collectivized science, according to Ziman, include costly research apparatus, increasing aggregation of research facilities, and collaboration in research performance that redefines "teamwork." In the words of the National Science Board, ". . . modern science and engineering research is more organized, capital intensive, multidisciplinary, and cooperative than in the past. Our universities must adapt to this need." National Science Foundation, "The State of U.S. Science and Engineering," A View From the National Science Board, statement accompanying *Science & Engineering Indicators—1989*, February 1990. These dimensions are discussed further in ch. 7.

Strong incentives militate against reducing research output. For instance, since most overhead is brought into the university by a small number of research professors (at Stanford, 5 percent of the faculty bring in over one-half of the indirect cost dollars[78]), proposals to reduce research output are not looked on with favor by many university administrations. Any measure that would curb the productivity of these professors would deprive the university of revenues. Thus, many universities try to *maximize* the level of research volume and output.[79]

OTA finds that research personnel at the two universities examined are experiencing relative deprivation. This would appear to be symptomatic of pressures felt on similar high-caliber research campuses. If so, then the Federal Government, by sending clear signals about the importance of scientific merit, education, and equity in allocation decisions, could aid universities in planning for a changing research economy (see box 6-E).

Responsiveness

Another factor leading to perceived instability in the research environment is the difference in time scales between changing national needs, on the one hand, and universities' capacity to respond to them, on the other. To build a research infrastructure, like any government contractor, universities must commit funds to construct facilities and to purchase equipment. If the Federal Government then decides to switch emphases, universities must continue to maintain this infrastructure. Also, no matter how resourceful one may be, there are few incentives for a professor to change research areas after having accumulated knowledge in one or two specialties.[80] It is perceived as being more cost-effective for the university to hire new younger faculty and build up their research capacity than to try to convert an older researcher to a new field. Consequently, researchers in universities have little recourse if research emphases shift dramatically in Federal support for their particular field.[81]

An example of a *growing* department at the University of Michigan may help illustrate some of these points. In 1980-81, the Electrical Engineering and Computer Science (EECS) Department was perceived as weak. The central administration at UofM decided to invest resources in the department and pursue expansion. Most importantly, it decided on a few key research priorities: optics, solid state electronics, robotics, and microelectronics. The administration encouraged retirement of many of the older faculty and "weeded out" a few others. It hired faculty in the designated areas to fill the vacant slots and added a few faculty positions as well. EECS expanded its research capacity in areas that the Federal Government presently supports. It has subsequently received more Federal funding. Unfortunately, EECS does not project, for the foreseeable future, the flexibility it experienced in the 1980s. The department attributes its flexibility to the hiring of new faculty, and doubts that this flexibility will continue as the faculty ages.

The development of EECS may be unique among university departments. As a survival tactic, universities have traditionally attempted to maintain broad departments, covering many subdisciplines, so that if funding in one area diminishes it has a minimal

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[77] See N.L. Geller et al., "Lifetime Citation Rates to Compare Scientists' Work," *Social Science Research*, vol. 7, 1978, pp. 345-365; and A.L. Porter et al., "Citations and Scientific Progress: Comparing Bibliometric Measures With Scientist Judgments," *Scientometrics*, vol. 13, 1988, pp. 103-124. The National Science Foundation now limits the number of publications it will consider, as evidence of an applicant's track record, in reviewing grant proposals. See Hamilton, op. cit., footnote 73.

[78] Rick Biedenweg and Dana Shelley, *1986-87 Decanal Indirect Cost Study* (Stanford, CA: Stanford University, February 1988), p. xii.

[79] For example, Donald Kennedy, president of Stanford University (SU), said in an OTA interview (Aug. 2, 1990) that if the 1990s do not promise great increases in the Federal science budgets, SU will have to institute four means to balance its budget, and the first three have already been introduced: 1) restructure the budget for SU and instigate cuts; 2) boost the research volume to bring in more research dollars; 3) lobby for increased facilities programs from the Federal Government; and 4) move some indirect costs to the direct cost lines to ensure full recovery.

[80] See John Ziman, *Knowing Everything About Nothing: Specialization and Change in Scientific Careers* (Cambridge, England: Cambridge University Press, 1987); and John Ziman, "Research as a Career," *The Research System in Transition*, S.E. Cozzens et al. (eds.) (Dordrecht, Holland: Kluwer, 1990), pp. 345-359. "The buildup of accumulated skills and knowledge puts a lot of inertia into the academic research system, and . . . a premium on expansion as the easiest route toward reorientation of priorities." Harvey Brooks, Harvard University, personal communication, February 1991.

[81] In the case of a national research mission, such as the War on Cancer, relabeling one's research to qualify for mission money was a workable strategy. See K.E. Studer and D.E. Chubin, *The Cancer Mission: Social Contexts of Biomedical Research* (Beverly Hills, CA: Sage, 1980), especially ch. 3.

Box 6-E—Emulating the Research University: Beware

In the last few decades, many universities have aspired to emulate the top research universities, in the hopes of gaining a larger share of the Federal research pie. However, in the 1990s, the model of a research university may become less attractive, functional, and reproducible.

Research universities are characterized by strength across departments and other units where research is performed. For instance, Stanford University is not known particularly for strength in one field, or even several, but for across-the-board excellence in every discipline—within science and engineering and without. Similarly, these universities are the major recipients of Federal research and development funds and train the largest cadre of new Ph.D.s in those disciplines.[1]

Outside the top 50 to 100 institutions are hundreds of universities that also compete for Federal research funding.[2] They reason that an influx of Federal monies could ease some of the financial burdens they face, but moreover, could boost their capacity to do research and attract still more funding from other sources. Arguably, the research university has been a model for emulation even for institutions whose missions and resource base made them unlikely candidates to join the top 100. Institutional mobility is rare, but does occur.

Unfortunately, beneath the surface of many successful research universities lie many fiscal problems connected with their research enterprise:

1. The demand for research funding is rising in some fields faster than funding available from Federal and other sources, and some universities claim they cannot keep up.
2. Demands for state-of-the-art facilities are increasing with little financial help from the Federal Government, so universities must tap State or private coffers to allow for renovation and new construction.
3. Charges abound that research faculty are shirking their teaching commitments, and students complain that their education has suffered.

These problems notwithstanding, there is still an allure—and a necessity—to pursue Federal research dollars. In addition to competing quite successfully for disciplinary agency support, universities are attracted by Federal initiatives that enjoy ''new'' priority funding. At the University of Michigan, for example, initiatives such as global

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[1] In fiscal year 1988, 10 universities received almost one-quarter of the Federal research and development funds awarded to all academic institutions. They were Johns Hopkins, Stanford, Massachusetts Institute of Technology, Wisconsin-Madison, Michigan, Washington, California-San Diego, Cornell, California-Los Angeles, and Columbia. See National Science Foundation, *Academic Science and Engineering: R&D Funds—Fiscal Year 1988*, NSF 89-326 (Washington, DC: 1990), table B-37. These same 10 universities produced 15 percent of all science and engineering Ph.D.s. (3,303 of 20,738) that year. National Science Foundation, *Science and Engineering Doctorates: 1960-89*, NSF 90-320 (Washington, DC: 1990), table 9. The distribution of honors, e.g., Nobel prizes and election to the National Academy of Sciences, reinforces the stratification among research universities and the role of a select few in the education and employment of U.S. scientists.

[2] For example, 1,719 institutions were supported by the National Institutes of Health (NIH) in 1990, but only 25 accounted for 38 percent of NIH's extramural funds. See ''NIH Policy Change Could Shake Up Distribution of NIH Extramural Funding, Official Says,'' *Washington Fax*, Nov. 23, 1990.

effect on the department as a whole. On the other hand, if one area receives increased support, the university will be prepared to take advantage. Due to increased competition for funds, the model of a multifaceted yet targeted department, such as EECS, may become more prevalent. Universities may find that concentrating their research capabilities in specific areas may enhance their competitiveness for Federal funding by augmenting their research track record and the availability of research facilities and equipment in those areas. Another tactic is the welcoming of non-Federal sources of research funding to campus, often to ''leverage'' Federal funding (see box 6-F).

In the current research economy, a broad base is increasingly difficult to maintain. Universities trying to achieve the status of the top 50 research institutions are bound to face numerous obstacles if they try to obtain—and sustain—success through a broad-based approach.

Summary

In this chapter, OTA has reviewed data on research expenditures from the perspectives of both the Federal Government and academic research performers. Fueled by increases in Federal, industrial, and academic spending on research, the national research effort and the levels of basic and

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climate change and the Human Genome Project are seen as "bandwagons": once the university commits resources to participate, it runs the risk of absorbing the costs of the research infrastructure and personnel after Federal support wanes.[3]

If the top research universities are struggling to maintain excellence, even with their inherent advantages, it may be unwise for other universities to try to become like them. It takes years to develop the breadth and depth of resources that makes a research university; it does not happen quickly.[4] Moreover, the classic research university model may simply be maladaptive for these times.[5] Maintaining the human and physical infrastructure that has accumulated over decades is a huge financial burden that affects all campus functions.[6]

Building targeted strength would appear to be a more sensible institutional strategy than striving for across-the-board excellence. Thus, one magnet laboratory funded by the National Science Foundation (and the State of Florida) will not transform Florida State University into a Massachusetts Institute of Technology. But Florida State might become world-class in research on high-energy magnetism. Such targeting demands concentrated fiscal and human resources, selective recruitment of faculty researchers, and construction of facilities. The Federal Government has a role to play in this effort. As recently stated: "It's the classic American challenge: What's the best tradeoff between the conflicting desires of preserving excellence and promoting diversity?"[7]

Preserving excellence in research and teaching at U.S. researching universities is not a Federal obligation; it is a good investment. Research universities have strategic plans, critical masses of researchers, and the reputation for selectivity. However, those institutions that aspire to join the select group of top research universities in the 1990s might best reconsider the research university model—and proceed at their own risk.

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[3] In the short run, resources that would have been devoted to instruction tend to get diverted to this high-profile research. Investing in fashionable research is an important part of the university portfolio, but the cost of some activities may have an adverse effect on others. This example is based on OTA interviews with University of Michigan administrators, July 1990.

[4] This was a recurrent theme at hearings held by the House Committee on Science and Technology, Task Force on Science Policy in 1985-86. For an analysis of members' and witnesses' concerns, see Patrick Hamlett, "Task Force on Science Policy: A Window on the Federal Funding and Management of Research," OTA contractor report, October 1990. Available through the National Technical Information Service, see app. F.

[5] See Linda E. Parker and David L. Clark, "Departmental Responses to Fluctuation in Research Resources," *Research Management Review*, vol. 4, spring 1990, pp. 19-34.

[6] Perhaps the most striking evidence of a university's research intensiveness is the number of postdoctorates it employs. By this measure, Stanford and Michigan are spectacular examples. At both institutions, postdoctorates in life sciences represent two to three times the number of postdoctoral appointees in all other fields combined. (Physical sciences is the runner-up on both campuses.) At Stanford, the number of life sciences postdoctorates doubled to 600 in 1988. This also represents almost twice the number of graduate (i.e., predoctoral) students in life sciences at Stanford. At Michigan the emphasis is reversed: although postdoctorates in life sciences grew from 160 to 280 between 1980 and 1988, the number of predoctoral students in these fields totaled three times the postdoctoral count. These differences in graduate students and postdoctoral numbers are probably reflected in the composition of research teams.

[7] Michael Schrage, "Blurring the Line Between Funding Science and Funding Economic Growth," *The Washington Post*, Oct. 5, 1990, p. F3.

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applied research individually are at levels surpassing the "golden age" of the 1960s. However, the rise in demand for funds from the research community continues to outpace Federal funding increases.

This rise in demand is due primarily to increased *spending* on research, and only secondarily to increases in the "costs" of individual components of research budgets. Increased spending appears to stem from the growth of the size of research groups under the direction of one principal investigator, a tendency toward growing pressure to produce more research, and an increasing complexity of equipment and facilities (although advances in technology can also decrease overall spending).

Reliable analyses of research expenditures by Federal agencies are not available. Information provided to the agencies by the performers is likely to combine actual need with the desire to pursue boundless opportunities in research. Some trends, however, are well documented. The number of scientists conducting research and supporting graduate and postdoctoral students has grown. Every agency has seen a growth in the number of grant applications submitted. In addition, average expenditures per investigator have nearly tripled, in real terms, since 1958. The obsolescence time for equipment and instrumentation has shrunk more than twofold, and facilities built in the 1950s and 1960s are in need of repair and renovation. The

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Box 6-F—Industry on Campus

Universities have been aggressive in seeking industry support for research in the 1980s, though the relationship between the two sectors has been a "two-way street" for more than a half-century.[1] Industry funding of university research, though brisk in the 1980s, still represented just over 5 percent of all university research. (The highest proportions are found at engineering institutions—Georgia Institute of Technology, Carnegie-Mellon, Massachusetts Institute of Technology.) Most of that funding was geared to generic, nonproprietary knowledge aided by support for faculty, graduate students, and infrastructure. In other words, technology transfer, patenting, and commercial gain were not the primary motivations for academic-industry relations.[2]

Until recently, only certain fields have had relevance to industry investment for a profit motive: computer science, metallurgy, materials science, and chemistry.[3] More recently, biology has offered industry new techniques for the development of products and processes. As historian Roger Geiger points out:

> The case for the importance of the university role in economic development rests on two pillars: that industry has been underinvesting in generic research, and thus could profitably utilize additional research from universities; and second, that discoveries of potential commercial value were being made in universities, but were not reaching the market because of linking mechanisms.[4]

In many fields, the demand for research funds are exceeding available funds from traditional sources—especially in fields that require large-scale, technologically advanced equipment and instruments, as well as more technicians with more skills. Concerns about sponsorship—military as well as industrial—skewing the research

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[1] Large chemical and drug companies funded university laboratories for routine services, like testing, beginning in the 1930s. See Roger L. Geiger, "Industry and University Research: The Revolution of the 1980s," *Science and Technology and the Changing World Order*, colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (ed.) (Washington, DC: American Association for the Advancement of Science, 1990), pp. 138-148; and Paul E. Gray, "Advantageous Liaisons," *Issues in Science & Technology*, vol. 6, No. 3, spring 1990, pp. 40-46.

[2] See Roger L. Geiger, "Milking the Sacred Cow: Research and the Quest for Useful Knowledge in the American University Since 1920," *Science, Technology, & Human Values*, vol. 13, Nos. 3-4, summer & autumn 1988, pp. 332-348.

[3] According to Richard R. Nelson, "Institutions Supporting Technical Advance in Industry," *American Economic Review*, vol. 76, May 1986, pp. 186-189.

[4] Geiger, op. cit., footnote 1, p. 147. For a case in point, see David Blumenthal et al., "University-Industry Research Relationships in Biotechnology: Implications for the University," *Science*, vol. 232, June 13, 1986, pp. 1361-1366; U.S. Congress, Office of Technology Assessment, *U.S. Investment in Biotechnology*, OTA-BA-360 (Washington, DC: U.S. Government Printing Office, July 1988); and Phyllis B. Moses and Charles E. Hess, "Getting Biotech Into the Field," *Issues in Science & Technology*, vol. 4, No. 1, fall 1987, pp. 35-41.

entire enterprise has grown at a rate above inflation and beyond what the current Federal budget can perhaps afford.

Competition for funds, coupled with a failure to meet research expectations on the part of many researchers, contributes to relative deprivation at many research universities. University researchers feel deprived because their resources (and subsequent outputs) have not met their expectations. Although many universities urge a quick infusion of money to ensure their responsiveness to national research missions as well as the scientific research base, from an "expenditures/costs" perspective, it may not be the appropriate role of the Federal Government simply to supply extra funds. Rather, the Federal Government could encourage both established and aspiring research universities to consider the funding environment and to adjust their research agendas, timetables, and needs accordingly.[82] Devising mechanisms for understanding and coping with research expenditures is one of the central challenges to the Federal system for funding research in the 1990s.

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[82] It should be noted that, under the Florida and Federal Demonstration Projects, no-cost extensions on research grants and other means of expanding the authority of universities to control research budgets locally have been successfully tested. By providing flexibility, these expanded authorities create opportunities for cost savings and improved accountability. See Anne Scanley and William Sellers, Government-University-Industry Research Roundtable, "Summary of Interim Reports Submitted by Grantee Organizations Participating in the Federal Demonstration Project," unpublished document, Oct. 1, 1990.

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agenda and undermining the spirit of open inquiry on campus are still voiced.[5] But the trend has not so threatened academic norms as to provoke a backlash.[6] Perhaps out of economic necessity, universities have accommodated.[7]

The "competitiveness" debate has legitimized academic involvement with industry, if not outright promoted it. There is an assumption that strengthening the links between industry and university research will improve America's economic malaise. A series of legislative and executive initiatives in the 1980s encouraged collaboration, such as the Patent and Trademark Amendments of 1980 (Public Law 96-517), the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480), the 1981 Economic Recovery Tax Act (Public Law 97-34), and the National Cooperative Research Act of 1984 (Public Law 98-462). In addition, the 1980s witnessed a growth of State economic development programs that aimed to stimulate university-industry cooperation in public universities. More and more, linkage between universities and industry has been viewed as essential and mutually beneficial.[8]

The resiliency of the university will continue to be tested by rising demands for research funds and the proliferation of missions served by experts on campus. In the 1990s, opportunistic funding of university research may give way to a moderation of corporate-sponsored research. Or such undertakings may continue to be physically segmented in a research institute or center as a way of detaching the industrial values it symbolizes from the core campus organization.[9] The existence of university-industry collaborations is not in doubt; the forms of these collaborations, however, will remain in flux.

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[5] For example, see "Secrecy in University-Based Research: Who Controls? Who Tells?" *Science, Technology, & Human Values*, special issue, vol. 10, No. 2, spring 1985, pp. 3-114; and Henry Etzkowitz, "The Second Academic Revolution: The Role of the Research University in Economic Development," *The Research System in Transition*, S.E. Cozzens et al. (eds.) (Dordrecht, Holland: Kluwer, 1990), pp. 109-124.

[6] It has made "intellectual property" an academic as well as a Federal policy issue. For discussions, see Marcel C. LaFollette, "U.S. Policy on Intellectual Property in R&D: Emerging Political and Moral Issues," in S.E. Cozzens et al., op. cit., footnote 5, pp. 125-139; and U.S. Congress, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and Information*, OTA-CIT-302 (Springfield, VA: National Technical Information Service, 1986). Also see Charles Weiner, "Universities, Professors, and Patents: A Continuing Controversy," *Technology Review*, vol. 89, No. 2, February/March 1986, pp. 33-43.

[7] For example, see George R. McDowell, "Land-Grant Colleges of Agriculture: Renegotiating or Abandoning a Social Contract," *Choices*, second quarter 1988, pp. 18-21.

[8] Office of Technology Assessment, op. cit., footnote 4. Also see Barry Bozeman and Michael Crow, "The Environments of U.S. R&D Laboratories: Political and Market Influences," *Policy Sciences*, vol. 23, No. 1, 1990, pp. 25-56.

[9] See Dorothy Nelkin and Richard Nelson, "Commentary: University-Industry Alliances," *Science, Technology, & Human Values*, vol. 12, winter 1987, pp. 65-74. In other words, the value of academic research is likely to persist, if not grow. See Edward M. Scolnick, "Basic Research and Its Impact on Industrial R&D," *Research-Technology Management*, November-December 1990, pp. 21-26.

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CHAPTER 7

Human Resources for the Research Work Force

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CHAPTER 7

Human Resources for the Research Work Force

My first priority is to create an environment in which talented young people choose careers in health sciences research. . . . My second priority would be to fashion a system in which talented, more senior researchers could obtain stable funding for their best work. Those two priorities cannot be achieved without setting some limits and making difficult choices.

Leon Rosenberg[1]

Introduction

The scientific education system in the United States, especially at the doctoral level, is the envy of the world. Foreign nationals continue to seek degrees in science and engineering at U.S. institutions at an ever growing rate, and this exemplary "production" of Ph.D.s has continued over at least the past 30 years.

The U.S. graduate research and education system trains new researchers and skilled personnel for all sectors of the Nation's work force (and for some countries abroad). While new researchers have traditionally been trained for faculty positions in academia, in fields like computer science, the demand for technical labor outside of academia is great. Some fields, like chemistry, also benefit from having a large set of potential academic and industrial employment opportunities. This diversity makes any labor market fluid and its forecasting difficult, but the major components can be analyzed.

This chapter focuses on Ph.D. production and employment in the United States and the *research* work force, as a subset of the total science and engineering work force. The educational "pipeline" that prepares students at the K-12 through undergraduate level for doctoral study is discussed where needed.[2] First, the chapter discusses the overall shape of Ph.D. production in the United States, the Federal role in supporting graduate education, and the present employment prospects for new Ph.D.s. Second, the chapter focuses on projections for future employment of Ph.D.s, and then turns to training considerations for an uncertain future. The chapter concludes with a discussion of the Federal role in Ph.D. production and employment for the 1990s.

Photo credit: U.S. Department of Energy

Scientist mixes a chemical sample. Broadening the participation in research of traditionally underrepresented groups, such as U.S. minorities, is a central issue for the health of the research enterprise.

Baseline Data on Science and Engineering Degrees

Trends in the award of science and engineering (s/e) degrees highlight 20 years of growth in human resources.[3] Scientific education has yielded a significant number of new Ph.D.s, yet the benefits of this education have not accrued equally to all groups and, therefore, to the Nation. Women and U.S. racial and ethnic minorities, despite gains in Ph.D. awards through the 1970s and 1980s, lag the achievement of white men. Relative to their numbers in both the general and the undergraduate populations, women and minorities are underparticipating in the research work force.[4] Foreign nationals on temporary visas are a growing proportion of s/e degree recipients.[5] National Science Foundation (NSF) data indicate the following trends.[6]

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[1] Quoted in Dick Thompson, "The Growing Crisis in Medical Science," *Time*, Dec. 17, 1990, p. 21.

[2] An analysis of the higher education stages of the pipeline and how the Federal Government intersects with it is contained in U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering*, OTA-BP-SET 52 (Washington, DC: U.S. Government Printing Office, March 1989).

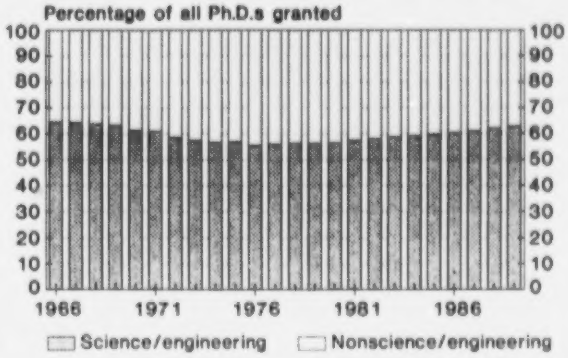
Degrees, Gender, Ethnicity, Nationality, and Fields of Study

The total number of Ph.D.s awarded in s/e has increased from 17,400 in 1977 to over 20,250 in 1988. In addition, the proportion of s/e Ph.D.s awarded as compared with Ph.D.s granted in all fields varied from 57 to 64 percent over the period from 1966 to 1988 (see figure 7-1).

Of the approximately 34,000 Ph.D.s awarded in 1988 (in all s/e and non-s/e fields), the distribution by *s/e field* ranges from 2 percent in environmental sciences to 15 percent in biological/agricultural (hereafter, "life") sciences. Trends in field shares are variable, showing percentage increases and decreases over the period 1966 to 1988 (see figure 7-2).

One in three college graduates earns the baccalaureate degree in an s/e field. By gender, men earn more baccalaureate degrees in s/e fields per thousand than women by a ratio of three to two.[7] In 1988, women earned 40 percent of baccalaureate degrees, 30 percent of master's degrees, and 27 percent of the doctorates awarded in s/e. At the Ph.D. level, this proportion represents more than a tripling since 1966 (see figure 7-3). (In non-s/e fields, however, women have achieved parity in Ph.D.s earned and exceed the numbers of men awarded baccalaureate and master's degrees.)

Figure 7-1—Ph.D.s Granted, by Field: 1966-88



SOURCE: National Science Foundation, *Science and Engineering Degrees: 1966-88, A Source Book,* NSF 90-312 (Washington, DC: 1990), table 1; and National Science Foundation, *Science and Engineering Doctorates: 1960-89,* NSF 90-320 (Washington, DC: 1990), table 1. National Science Foundation, *Science and Engineering Degrees: 1966-88, A Source Book,* NSF 90-312 (Washington, DC: 1990), table 1; and National Science Foundation, *Science and Engineering Doctorates: 1960-89,* NSF 90-320 (Washington, DC: 1990), table 1.

Except for life sciences, psychology, and social sciences, the number of doctorates awarded to women is modest. In 1988, among U.S. citizens, men earned 90 percent of the engineering Ph.D.s, 63 percent of the science Ph.D.s, and 48 percent of the non-s/e Ph.D.s. In fractional terms, women now earn one in three life sciences and social sciences Ph.D.s and more than one of every two Ph.D.s awarded in psychology. From 1966 production rates, engineer-

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[3] Although OTA uses the shorthand "scientists and engineers," it recognizes the diversity of fields represented by the term. These fields are those used as degree-granting categories in the National Science Foundation's Science Resources Studies reports: engineering, physical sciences, environmental sciences, mathematical sciences, computer/information sciences, life (biological/agricultural) sciences, psychology, and social sciences.

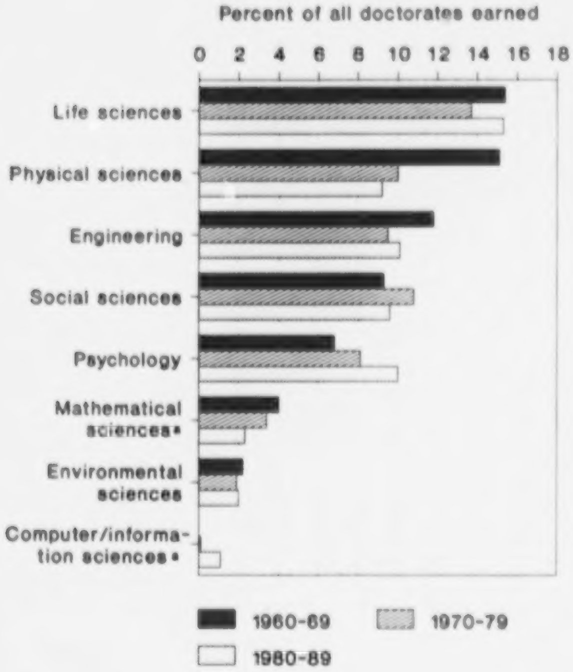
[4] Degrees alone tell an incomplete story of future supply of scientists and engineers. For example, college attendance rates of 18- to 21-year-olds vary by gender and race. Since 1972, 35 to 40 percent of whites of both sexes in the cohort have attended college with Black rates in the 25 to 30 percent range. By 1988, female attendance exceeded that of males and was rising, whereas male attendance of both races peaked in 1986-87 and has declined thereafter. See National Science Board, *Science & Engineering Indicators—1989* (Washington, DC: U.S. Government Printing Office, 1989), figure 2-2, p. 50. The National Science Foundation furnishes all data reported in the *Science & Engineering Indicators* report.

[5] For an overview, see Commission on Professionals in Science and Technology, *Measuring National Needs for Scientists to the Year 2000*, report of a workshop, Nov. 30-Dec. 1, 1988 (Washington, DC: July 1989), pp. 20-24. For more on graduate engineering education, see Elinor Barber et al., *Choosing Futures: U.S. and Foreign Student Views of Graduate Engineering Education* (New York, NY: Institute of International Education, 1990).

[6] National Science Foundation, *Science and Engineering Degrees: 1966-1988—A Source Book*, NSF 90-312 (Washington, DC: 1990). Doctorate data are drawn from the multiple agency-sponsored Survey of Earned Doctorates conducted under contract by the National Research Council and assembled and reported by the Division of Science Resources Studies of the National Science Foundation.

[7] This ratio has narrowed since 1966 when it was nearly 3.5 to 1. See ibid., table 55, p. 43. Also see Sarah E. Turner and William G. Bowen, "The Flight From Arts and Sciences: Trends in Degrees Conferred," *Science*, vol. 250, Oct. 26, 1990, pp. 517-521.

Figure 7-2—Distribution of Doctorates by Science and Engineering Field, 1960-90
(by decade, in percent)



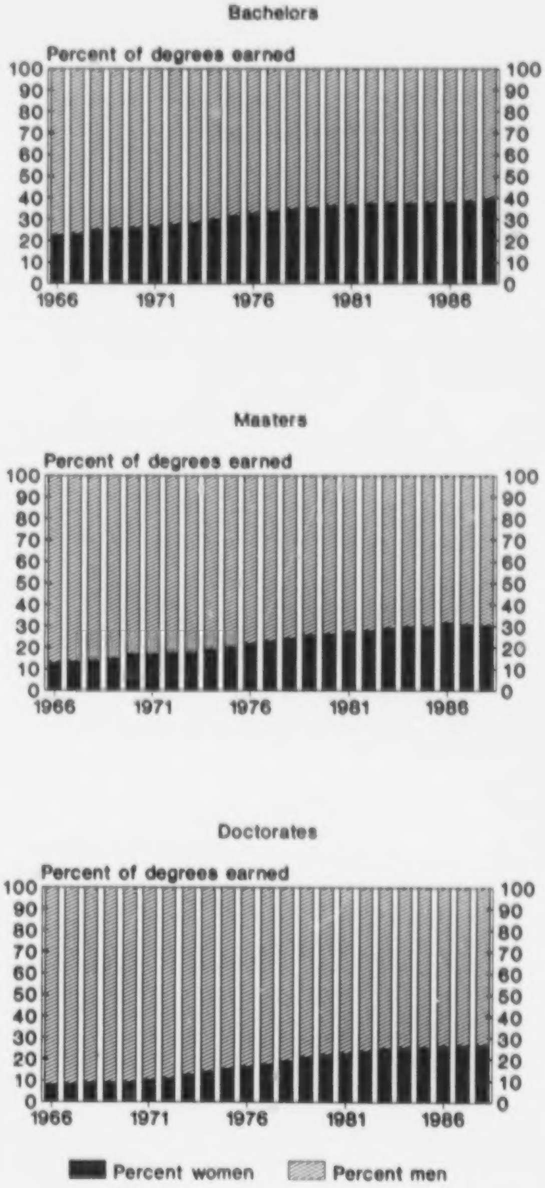
[a] Degrees in this field were not awarded until the late 1970s; before then, computer science was counted with mathematical sciences.

SOURCE: National Science Foundation, *Science and Engineering Doctorates: 1960-89*, NSF 90-320 (Washington, DC: 1990), table 1.

ing increased from virtually no awards to women to almost 7 percent in 1988, while physical sciences experienced a fourfold increase to 17 percent.[8]

The total number of Ph.D.s in s/e awarded to *minorities* rose from 560 in 1975 to 1,100 in 1988. However, trends by ethnic group are not as consistent. Black U.S. citizens earned 240 Ph.D.s in 1975, which rose to a high of 290 in 1979, but by 1988 had dropped to 230. Degrees awarded to Hispanics over the same period increased from 130 in 1975 to 320 in 1988, exhibiting predominantly steady increases each year. The most dramatic increase occurred within the Asian population, which recorded increases from 190 Ph.D.s in s/e in 1975 to 440 Ph.D.s in 1988, with gains posted in every year but one (1985).[9]

Figure 7-3—Science and Engineering Degrees, by Level and Sex: 1966-88



SOURCE: National Science Foundation, *Science and Engineering Degrees: 1966-88, A Source Book*, NSF 90-312 (Washington, DC: 1990), tables 3 and 4.

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[8] National Science Board, op. cit., footnote 4, tables 23 and 25, pp. 25-26.

[9] Ibid., pp. 55-56. The numbers have been rounded.

Foreign citizens on temporary visas earn increasing proportions of the s/e doctorates awarded by U.S. universities: one-quarter of all s/e Ph.D.s, and as much as 40 percent in engineering and mathematics.[10] The number of Ph.D.s awarded in s/e to foreign citizens on temporary visas increased from 2,700 in 1975 to 4,800 in 1988, with the most rapid gains in the 1980s. Foreign nationals on permanent visas, on the other hand, decreased from 1,200 in 1975 to 820 in 1984, but experienced a rapid rise to 1,100 in 1988. At the same time, the total for U.S. citizens dropped from 14,000 in 1975 to 12,800 in 1988, with the most rapid decrease in the late 1970s. During the 1980s, s/e Ph.D.s awarded to U.S. citizens showed no clear trends, ranging from a low of 12,600 (1987) to a high of 13,300 (1981).[11]

In summary, the total number of Ph.D.s awarded in s/e in the United States has increased by nearly 50 percent from 1977 to 1988. The numbers of women and minority recipients of Ph.D.s have also increased, with the greatest gains posted by women, Hispanics, and Asians, but with no gain by Blacks. Perhaps most dramatic is the increase in Ph.D. awards to foreign citizens on temporary visas, which almost doubled from 1978 to 1988. (For a comparison of national trends with the experiences of four research universities—public and private, and regionally dispersed—see box 7-A.)

Forms of Federal Support to Graduate Students

Clearly, graduate enrollments and the award of the Ph.D. in s/e depend on more than undergraduate degree attainment. Institutional practices and Federal policies play a significant role in graduate student support, completion of the doctorate, and employment aspirations. OTA notes the following trends.

Ever since the National Defense Education Act of 1958 (NDEA, Public Law 85-864) passed in the wake of the Sputnik launch, the Federal Government has been pivotal in pre- and postdoctoral support of science, engineering, and indeed, non-s/e students.[12] Additional programs were soon established by NSF, the National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), and other Federal agencies. This period of growth, beginning in the 1960s, in Federal programs offering *fellowships* (portable grants awarded directly to students for graduate study) and *traineeships* (grants awarded to institutions to build training capacity) was followed by decreases in the 1970s.[13] In the natural sciences, these declines were offset by the rise in the number of *research assistantships* (RAs) awarded on Federal research grants. Federal support to the humanities and social sciences has always been comparatively less since, outside of NDEA, traineeships and fellowships were offered for the natural sciences, and research assistantships are rarely supported on social sciences or humanities grants. During the 1980s, other sources of support, including loans and family contributions, remained constant (see figure 7-4).

In the 1980s, RAs became the principal mechanism of graduate student support, increasing at 5 percent per year since 1980 (except in agricultural sciences, where RAs have actually declined). This trend is consistent with the growing "research intensiveness" of the Nation's universities: more faculty report research as their primary or secondary work activity, an estimated total in 1988 of 155,000 in academic settings.[14]

If the Federal agencies were to change the mix of support to graduate students, first by increasing the number of portable fellowships, the concentration of support in the major research universities would be reinforced. On the other hand, if the government were to increase the number of traineeships, Federal support could be directed to a broader set of institutions. No particular mix of support mecha-

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[10] Ibid., pp. 46, 56.

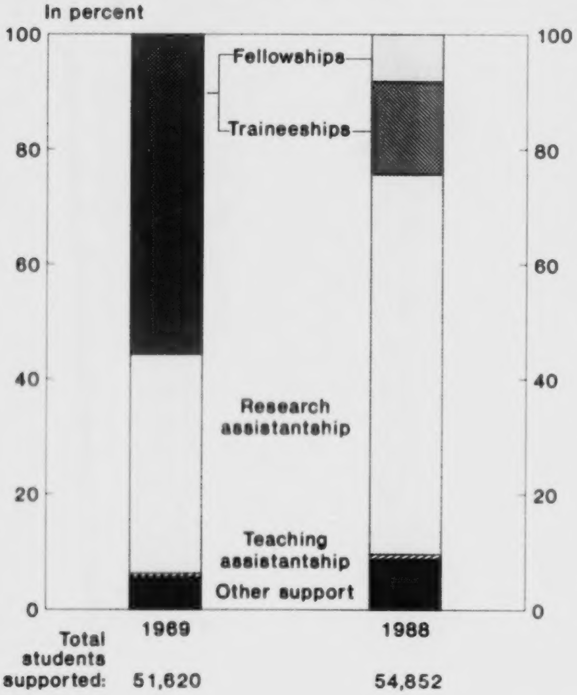
[11] Note that the numbers of Ph.D.s awarded to U.S. citizens and to foreign citizens on temporary and permanent visas do not add up to the number given for all Ph.D.s awarded. Roughly 7 percent of the total number of Ph.D.s are of unknown citizenship. Lawrence Burton, Science Resources Studies, National Science Foundation, personal communication, Dec. 10, 1990.

[12] For details, see U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force*, OTA-TM-SET-35 (Springfield, VA: National Technical Information Service, December 1985), pp. 44-49.

[13] Association of American Universities, *The Ph.D. Shortage: The Federal Role* (Washington, DC: Jan. 11, 1990), pp. 15-16.

[14] These 155,000 represent 37 percent of employed Ph.D. scientists and engineers in the United States in 1987. There are several assumptions built into these estimates—that Ph.D.s are most likely to do research, that research is considered a "primary or secondary research activity" by survey respondents, and that (although R&D are coupled here) basic and applied "R," not "D" is performed in academic settings. National Science Board, op. cit., footnote 4, pp. 46, 57, 115.

Figure 7-4—Federal Support of Science and Engineering Graduate Students: 1969 and 1988 (by type of support)



NOTE: Fellowships and traineeships were not reported separately in 1969.

SOURCE: National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 2-18; and National Science Foundation, *Graduate Student Support and Manpower Resources in Graduate Science Education, Fall 1969*, NSF 70-40 (Washington DC: September 1970), table C-11a.

nisms appears to alter the decision to pursue graduate study.[15]

Employment of Researchers

Since 1980, NSF estimates that the total s/e work force (baccalaureate, master's, and Ph.D. degree recipients) has grown at 7.8 percent per year, which is four times the annual rate of total employment of 1.8 percent. Scientists and engineers represented 2.4 percent of the U.S. work force in 1976 and 4.1 percent in 1988.[16] Almost 2.0 million scientists and 2.6 million engineers were employed in the s/e work force in 1988. In addition, almost 25 percent of all scientists and 10 percent of all engineers were employed in non-s/e jobs in 1988. At the doctoral level, scientists numbered 351,000, which is five times the engineers at 68,000. Total employment for doctoral scientists and engineers grew by nearly 5 percent per year from 1981 to 1987.[17] The percentage of foreign nationals who remain in the United States after receiving their Ph.D.s remained at roughly 50 percent through the latter half of the 1980s.

A pivotal employment sector for Ph.D. s/e researchers is academia. From 1977 to 1987, the number of Ph.D. scientists and engineers engaged in academic research increased by 65 percent. Figure 7-5 shows that life scientists accounted for one in three doctoral scientists and engineers on campus, a proportion unchanged in a decade, while figure 7-6 indicates average annual growth rates by field, with computer and information scientists leading the way.

The academic research work force in 1987 was 90 percent white (both sexes) and 84 percent male. Overall participation in academic research by minorities is bifurcated—9 percent is Asian and expanding, 2 percent is Black and Hispanic and barely inching upward. The most encouraging statistics are for Black women who, in 1987, represented 31 percent of Black Ph.D. scientists doing research in the academic sector.

NSF estimates a 51-percent increase, from 1977 to 1987, in the number of s/e doctorates engaged in *basic research*, regardless of employment sector. Four out of five (79 percent) worked in academia in 1987 (see figure 7-7); industry employs 8.6 percent; the Federal Government employs 6.7 percent; nonprofit institutions support 3.5 percent; and other groups employ the final 2.6 percent.

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[15] U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), p. 88. The administration's fiscal year 1992 budget, however, proposes to consolidate graduate student financial aid programs at the Department of Education into a single National Graduate Fellowships Program (NGFP) and place it under the discretionary authority of the Secretary of Education. Included under NGFP is the Graduate Assistance in Areas of National Need Program to support physical science and engineering students ($25 million in fiscal year 1991). See "FY 1992 Budgets for Social and Behavioral Science Research," *COSSA Washington Update*, vol. 10, Mar. 4, 1991, pp. 10-11.

[16] National Science Board, op. cit., footnote 4, p. 67.

[17] Ibid., p. 116.

Box 7-A—Institutional Variations on National Trends: Graduate Enrollments at Four Research Universities

While national trends in graduate enrollments, demography, support, and distribution by field paint the "big picture," they depersonalize and often mask how institutions (and their sponsors) influence those destined to join the research work force. Profiles of graduate student enrollments at four research universities—two public, two private—provide comparisons among key characteristics.[1]

In the 1980s, graduate enrollments grew by 18 percent nationally. By broad field, enrollments have, in percentage terms, grown steadily in engineering and mathematics/computer science, decreased slightly in the life sciences and more markedly in the social sciences, and been stable in psychology and the environmental sciences. But these national trends are not mirrored at the four universities examined by OTA: the University of Houston, the University of California-Santa Barbara (UC-Santa Barbara), Carnegie-Mellon University, and the Massachusetts Institute of Technology (MIT) (see table 7A-1).

Growth in enrollments from 1980 to 1988 range from 43 percent at Carnegie-Mellon to 13 percent at UC-Santa Barbara. MIT's enrollment declined by 2 percent. The University of Houston, while increasing its graduate student population by one-third, experienced the largest growth in mathematics/computer science. At Carnegie-Mellon, there was virtually no change in the distribution by broad field during the decade. At MIT, engineering enrollments declined (but over one-half of all graduate students there are pursuing engineering degrees), and at UC-Santa Barbara the number of mathematics/computer science students nearly tripled.

Examined in terms of demographic characteristics, the graduate student populations at all four universities reflect national trends, but at different levels:

- Nationally, the proportion of women is up slightly to 32 percent. At the four universities highlighted here the trend is similar, but enrollments of women averaged one-quarter of all science and engineering (s/e) students.
- Foreign nationals comprise almost one-half the graduate s/e students at Houston, and one-third at MIT and Carnegie-Mellon. Nationally, foreign students were 26 percent of the graduate student population in 1988.
- Among U.S. citizens, minorities represent one-quarter at Houston, but only 13 to 14 percent at the other three universities. The national average, unchanged since 1983, was 18 percent.[2]

In actuality, little is known about Ph.D. supply.[3] In the words of the National Research Council: "Basic descriptive statistics such as the percent of entering doctoral students who never complete the degree are unknown. More complicated issues such as determinants of degree completion (e.g., financial support, family responsibilities, demography, and time to complete the degree) remain unanswered."[4] National trends in graduate student enrollments tell only part of the story of factors affecting the renewal of human resources in science and engineering.

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[1] The data reported below are based on unpublished National Science Foundation data compiled by the Division of Science Resources Studies.

[2] The national data are drawn from National Science Board, *Science & Engineering Indicators—1989* (Washington, DC: 1989), pp. 215-216, tables 2-7 and 2-8.

[3] This sample of four institutions alone suggests that research-intensive universities may under-enroll women and U.S. minorities and over-enroll foreign nationals in graduate science and engineering study relative to national trends. OTA's analysis of University of Michigan and Stanford University is consistent with these findings across all fields of science and engineering as well, with women compromising 28 and 22 percent, respectively, and foreign nationals 34 and 30 percent, of graduate enrollments. But generalizations are premature until more systematic analysis is undertaken.

[4] Alan Fechter, executive director, Office of Scientific and Engineering Personnel, National Research Council, personal communication, Oct. 23, 1990.

Fields vary in their dependence on sectors of employment. Basic researchers with a Ph.D. in some fields—mathematics, sociology/anthropology, and economics—are employed almost exclusively in academia. Industry, in contrast, employed 19 percent of all engineers and 25 percent of computer scientists doing basic research in 1987. The field experiencing the largest percentage increase in industrial employment during the decade was the life sciences (in large part due to the biotechnology boom).[18]

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[18] Ibid. The National Science Foundation also reports that retention of male doctoral scientists and engineers is the highest for the business/industry and university/college sectors, around 80 percent, after 14 years (see pp. 117-118 for a discussion).

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Table 7A-1—Graduate Enrollment in Science and Engineering at Selected Universities, by Field: 1980-88

National totals

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
1980	208,232	20.1%	27.7%	21.8%	7.3%	10.4%	10.7%	4.9%
1983	223,135	23.6	21.5	20.0	8.8	9.9	11.0	5.2
1986	236,741	24.9	19.9	19.2	10.6	9.3	11.4	4.6
1988	245,463	25.1	20.1	19.1	10.8	9.5	11.3	4.0

University of Houston

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
1980	766	24.8%	12.7%	20.3%	9.5%	15.5%	14.3%	2.7%
1983	864	31.1	9.6	16.9	13.0	5.7	18.9	4.9
1986	1,165	29.0	9.5	13.6	13.7	14.2	16.5	3.4
1988	1,017	29.1	9.5	14.2	13.1	15.5	15.6	2.9

Carnegie-Mellon University

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
1980	796	47.4%	18.8%	2.9%	18.2%	1.6%	10.9%	0.0%
1983	965	44.0	21.7	3.2	18.8	2.1	10.3	0.0
1986	1,115	46.4	17.9	3.3	20.3	1.7	10.4	0.0
1988	1,137	45.8	18.6	3.5	19.5	2.5	10.0	0.0

Massachusetts Institute of Technology

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
1980	3,904	62.0%	10.2%	7.5%	3.0%	0.8%	12.9%	3.5%
1983	3,795	61.6	10.8	7.1	2.9	0.9	13.0	3.6
1986	3,925	56.2	11.6	6.4	8.1	1.1	13.0	3.5
1988	3,827	54.0	11.9	6.3	3.5	1.4	13.9	3.5

University of California-Santa Barbara

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
1980	1,142	25.2%	27.8%	17.4%	4.9%	4.5%	14.5%	5.6%
1983	1,178	27.6	25.6	16.0	4.8	4.1	16.1	5.9
1986	1,262	24.2	25.0	14.4	12.0	4.3	15.1	4.9
1988	1,293	28.3	22.0	14.6	13.4	3.7	13.9	4.0

NOTE: Full-time students only.

SOURCE: National Science Board, *Science & Engineering Indicators—1989* (Washington, DC: U.S. Government Printing Office, 1989), table 2-16, p. 228; and National Science Foundation, Institutional Profiles of the University of Houston, Carnegie-Mellon University, Massachusetts Institute of Technology, and University of California-Santa Barbara, unpublished information, 1989.

Complicating the understanding of employment trends is that temporary, 1- to 2-year appointments are a tradition in some fields. Postdoctoral appointments are used both to augment the specialized skills acquired in doctoral study and to wait out poor employment markets.[19] The number of Ph.D.s taking postdoctoral positions in U.S. universities has grown 5 percent annually since 1980. The availability of these appointments expand with academic research budgets, and over one-half of these posi-

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[19] Traditionally, the postdoctoral appointment is for 1 to 2 years. The last major national study of postdoctorates, however, is a decade old. This issue needs to be revisited empirically. For a national perspective, see National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981). For a first-person perspective on how circumstances may be changing, see Edward J. Hackett, "Science as a Vocation in the 1990s," *Journal of Higher Education*, vol. 61, May/June 1990, pp. 241-279.

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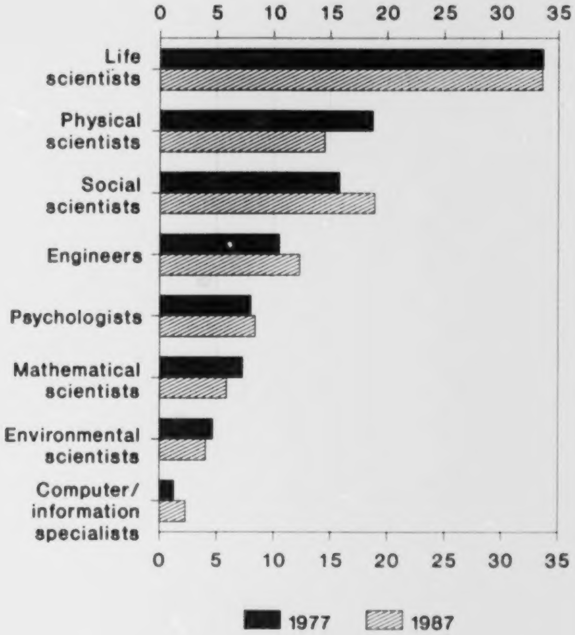
Figure 7-5—Distribution of Doctoral Scientists and Engineers in Academic R&D, by Field: 1977 and 1987 (In percent)

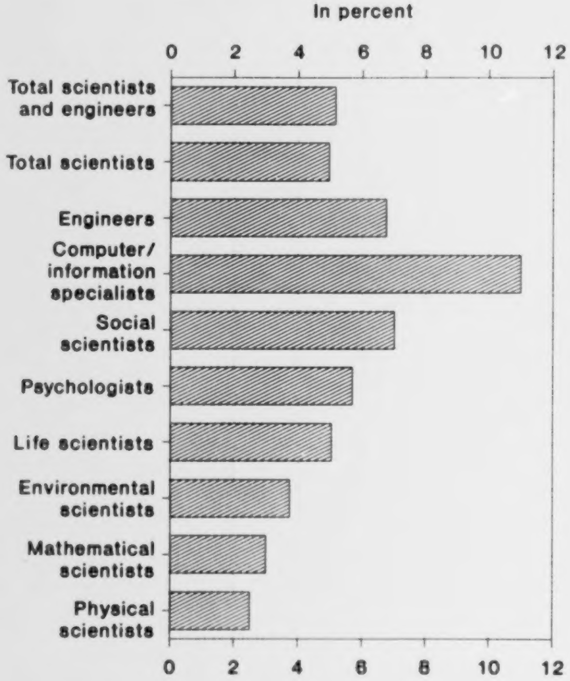


SOURCE: National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 5-17.

tions are located in the life sciences. Foreign citizens have been increasing their postdoctoral appointments at a rate twice that of U.S. citizens in the last decade.[20] Also, universities have increased the number of available nonfaculty research positions, and that the number of nonfaculty researchers as a percentage of the total number of Ph.D.s in s/e employed in academia rose from 14.8 percent in 1977 to 17.5 percent in 1987 (see box 7-B).

In sum, there is a steady stream of new entrants to the research work force. Almost 14,000 s/e Ph.D.s are granted each year by U.S. universities to U.S. citizens (nearly 13,000) or to foreign citizens who are permanent residents (over 1,000). Industry and academia have increased their employment of Ph.D.s in s/e over the past two decades, and by rates

Figure 7-6—Average Annual Percentage Growth Rate of Doctoral Scientists and Engineers in Academic R&D, by Field: 1977-87



SOURCE: National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 5-17.

exceeding 5 percent per year in the 1980s. In addition, relatively temporary university positions, such as postdoctoral and nontenure-track research slots, have increased.

Historically, the Federal Government has played both a direct and indirect role in the production and employment of s/e Ph.D.s. Both as the primary supporter of graduate student salaries and tuition, and as an employer through the Federal laboratories and mainly through research grants, the Federal Government has perhaps the largest role in the s/e Ph.D. labor market. With changing demographics and demands on the research component of this labor

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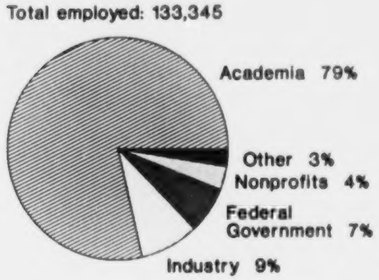
[20] National Science Board, op. cit., footnote 4, p. 54. There is both a "push" and "pull" factor operating in the postdoctorates taken by non-U.S. citizens with Ph.D.s. They may be ineligible for employment in some sectors, e.g., defense, and they can be productive researchers while awaiting a change in visa status from temporary to permanent. S. 358, passed in the 101st Congress, would allow the annual number of employment-based visas to increase from 54,000 to 140,000. Up to 40,000 visas are reserved for academicians and others with "extraordinary" ability to work in the United States. An annual cap of 65,000 H-1, or temporary professional, visas was also imposed. See Janice Long, "U.S. Immigration Eased for Professionals," *Chemical & Engineering News*, vol. 68, No. 47, Nov. 19, 1990, p. 13.

Figure 7-7—Employment of Doctoral Scientists and Engineers in Basic Research, by Sector: 1987



SOURCE: National Science Board, *Science & Engineering Indicators—1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 5-19.

force, the Federal Government could redefine that role as more or less interventionist in the 1990s.

The Shape of the Future Research Work Force

In recent years, the scientific community and some Federal research agencies have intensified the call for increased support of human resources. One emphasis has been on the educational "pipeline"—how to attract more elementary and secondary school students to science, mathematics, and engineering.[21] Since the school-aged population will begin to grow with the second baby boom in the mid-1990s, most research agencies have initiated programs that emphasize earlier stages in scientific education, especially at the secondary and undergraduate levels.[22] Not only will this population grow, but a larger proportion of it will consist of racial and ethnic minorities.

The Uncertainty of Ph.D. Projections

Another focus of concern is the state of graduate education in s/e. Some recent reports have projected that, in the 1990s, many scientific fields will experience shortages in the supply of Ph.D. researchers.[23] Based on demographic characteristics alone, NSF has estimated that the number of new Ph.D.s awarded in the natural sciences and engineering by U.S. universities (to U.S. citizens and foreign nationals) would rise from roughly 14,450 in 1988 to 15,600 in 1993, but then would decrease to 14,200 by the year 2010. This projection, based on a predicted "shortfall" in natural science and engineering baccalaureate degrees, assumes little change in the proportion of U.S. doctorate-seeking students and that the number of Ph.D.s awarded to foreign nationals remains at 4,500 per year.[24]

To convert these figures into a future supply of Ph.D.s for the scientific labor market, one must assume that some proportion of foreign nationals will seek to remain in the United States for employment. Most estimates assume that the current level of 50 percent will hold throughout the 1990s, while noting that increased scientific sophistication of these students' native countries may eventually draw a larger proportion of them back home.

If the current demand for Ph.D.s in academia and industry, at over 12,000 per year, were to remain constant, then the aggregate supply of Ph.D.s in the 1990s would be more than adequate. (This would not mean, of course, that the distribution among s/e

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[21] For a review of the factors influencing the early stages of the pipeline, see U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988); and D.E. Chubin, "Misinformation and the Recruitment of Students to Science," *BioScience*, vol. 40, No. 7, July/August 1990, pp. 524-526.

[22] The National Science Foundation has been particularly active. See Erich Bloch, "Education and Human Resources at the National Science Foundation," *Science*, vol. 249, Aug. 24, 1990, pp. 839-840; National Science Foundation, "Background Material for Long-Range Planning: 1992-1996," NSB-90-81, prepared for a meeting of the National Science Board, June 14-15, 1990, p. A-5; Ward Worthy, "Research Universities Pay More Heed to Freshman Science," *Chemical & Engineering News*, vol. 68, No. 18, Apr. 30, 1990, pp. 27-28; and Mac Van Valkenburg, "Turning Off Students: Our Gatekeeper Courses," *Engineering Education*, vol. 80, No. 6, September/October 1990, p. 620. For a new conceptualization of undergraduate recruitment and retention, see Sheila Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier* (Tucson, AZ: Research Corp., 1990).

[23] For example, see Association of American Universities, op. cit., footnote 13; Janice Long, "Changes in Immigration Law Eyed To Avert Shortage of U.S. Scientists," *Chemical & Engineering News*, vol. 68, No. 34, Aug. 20, 1990, pp. 19-20; and Richard C. Atkinson, "Supply and Demand for Scientists and Engineers: A National Crisis in the Making," *Science*, vol. 246, Apr. 27, 1990, pp. 425-432. Labor economist Michael Finn has noted that "shortage" is a relative concept. "Increasing shortage of scientists and engineers" means that they will be harder to find than they are now, or were in the recent past. The difficulty in measuring shortage is that hiring standards and personnel budgets adapt to supply and demand conditions. See Michael G. Finn, "Personnel Shortage in Your Future?" *Research-Technology Management*, vol. 34, No. 1, January-February 1991, pp. 24-27.

[24] Cited in Atkinson, op. cit., footnote 23.

Box 7-B—The Unfaculty: Who Are They and Why Should We Worry?

Graduate student enrollment increased rapidly during the 1960s, followed by a decline in the rate of increase in the 1970s and early 1980s. Because undergraduate and graduate student enrollment levels are closely associated with funding available for faculty salaries, it is not surprising that there was a decline in faculty job openings and a rise of "academic marginals" or research professionals, most possessing the Ph.D. but lacking a faculty appointment. This cadre has also been referred to as the "unfaculty," "unequal peers," or "research associates." In an effort to maintain an appropriate research base in the face of increasingly tight budgets, universities employ academic marginals on short-term contracts. These new nonfaculty positions do not depend on enrollment levels and afford the university flexibility in fulfilling its research needs since marginal positions are more readily emptied and reallocated than are tenured and tenure-track faculty.[1]

Who are these academic marginals? Many are postdoctoral fellows who, unable to secure faculty positions, remain in the university setting for an indefinite period of time. These positions might be viewed as extensions of the scientific apprenticeship system, which includes graduate education and postdoctoral training.[2] Of the fiscal year 1972 graduates who had taken postdoctoral appointments, approximately one-third had prolonged their appointments because they could not find other desirable employment.[3] Consequently, these professional research scientists tend to be highly qualified and capable, most earning Ph.D.s from reputable research institutions, have impressive publication records, and are supported by National Institutes of Health and National Science Foundation (NSF) grants.[4] Yet, academic marginals are not recognized as full faculty members; they receive none of the amenities and privileges of faculty and, more important, are ineligible for tenure.

The inferior status associated with the unfaculty fosters negative feelings and tensions within the research community. Comparatively low salaries, little job security, and limited "rights" to laboratory and office space or seed money and equipment all contribute to an environment in which the marginal scientist commands little respect from his or her full faculty peers. In fact, academic marginals often are dependent on faculty to provide part-time teaching or research that augments employment. Similarly, the academic marginal might find it difficult to establish him or herself in the scientific community at large: lacking an established laboratory and the accompanying prestige, marginal scientists have a ". . . longer row to hoe than most . . . [and] have to be more perfect."[5]

Standards vary on the research status of unfaculty and are a source of debate on many campuses. For example, research associates at Stanford University cannot act as principal investigators on research grants, which prohibits

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[1] U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989), p. 176.

[2] Edward J. Hackett, "Science in the Steady State: The Changing Research University and Federal Funding," OTA contractor report, 1987, p. 18. Available through the National Technical Information Service, #PB 88-177 928/AS.

[3] National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p. 225.

[4] Hackett, op. cit., footnote 2; and Albert H. Teich, "Research Centers and Non-Faculty Researchers: A New Academic Role," *Research in the Age of the Steady-State University*, Don Phillips and Benjamin Shen (eds.) (Boulder, CO: Westview, 1982), p. 100.

[5] See Edward J. Hackett, "Science as a Vocation in the 1990's," *Journal of Higher Education*, vol. 61, May/June 1990, pp. 253-254.

fields would be "correct.") However, these calculations further project that the demand for Ph.D.s, which has been rising in the 1980s, will continue to increase. Several factors are cited: 1) replacement of currently employed s/e researchers due to retirements and deaths; 2) rising college and university enrollments in the mid-to-late 1990s to accommodate the second baby boom (therefore requiring more faculty); and 3) increasing Federal and industrial investment in R&D, if only at a moderate rate.[25]

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[25] Research universities have the resources to plan for possible discontinuities in faculty age and tenure status. Other categories of institutions, especially comprehensive universities and 4-year colleges, will have less latitude in coping with imbalances in faculty supply and demand, which may be exacerbated with recision of the mandatory retirement law in 1993. Some alternatives, including the consolidation or elimination of departments and how, if at all, retiring faculty will be replaced, are discussed in Marcia Barinaga, "Howard Schachman Fights Retirement," *Science*, vol. 249, Sept. 14, 1990, pp. 1235, 1237; Constance B. Bouchard, "The 'Lost Generation' of Scholars Can Help Colleges Avoid the Looming Faculty Shortage," *The Chronicle of Higher Education*, vol. 37, No. 12, Nov. 21, 1990, pp. B1-B2; and Courtney Leatherman, "End of Mandatory Retirement Policies Seen Having Little Effect on Professors," *The Chronicle of Higher Education*, vol. 37, No. 17, Jan. 9, 1991, pp. A13-A14.

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them from gaining a history of funding with any Federal research agency. (This arrangement is fairly typical for research associate positions across the United States.)

It is possible that academic marginals are merely the product of a research environment that is shifting its focus and reevaluating its needs. But evidence that women have long been marginalized—less likely than men to land faculty posts or receive tenure once in them—in scientific research is unequivocal.[6] So funding pressures alone cannot explain swelling of the ranks of the unfaculty. Like the rest of the research work force, a panoply of demographic and funding changes may redefine the perceived needs of research universities. The status of those funded entirely on soft money may be reassessed as the costs of sustaining research units are scrutinized by academic administrators.

Surprisingly, national data beyond per-investigator costs are scarce on various "production" units of research. This includes the extent to which the ranks of academic marginals are growing. Unpublished data on research personnel at 4-year colleges and universities compiled by NSF (which warns that the data may not be comparable for different years) are presented in table 7B-1. Over the period 1977 to 1987, the proportion of Ph.D.s without faculty rank grew slightly. Growth in the number of unfaculty, up 15,000 in the decade to a total of 37,000, suggests that this is a sizable reserve research labor force to augment university faculty capabilities. Beyond that, little is known about:

Table 7B-1—Research Personnel at 4-Year Colleges and Universities (based on self-identification)

	1977	1981	1987
Ph.D.s with faculty rank (assistant, associate, full)	85.2%	83.9%	82.5%
Ph.D.s without faculty rank (includes postdoctorates)	14.8%	16.1%	17.5%
Total number	157,000	179,000	209,000

SOURCE: National Science Foundation, Science Resources Studies Division, unpublished data, July 1990.

1. the cost to the Federal Government, which pays the salaries of unfaculty who are supported on research grants;
2. the career paths and prospects of the unfaculty; and
3. the possible mobilization of the unfaculty in the face of impending faculty retirements in the 1990s and projected shortages of Ph.D. scientists and engineers early in the next century.

Until better information is collected and analyzed on the unfaculty, Federal policymakers must worry about who they are and how they affect the university research economy of the 1990s.

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[6] See Margaret W. Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (Baltimore, MD: The Johns Hopkins University Press, 1982); Pnina G. Abir-Am and Dorinda Outram (eds.), *Uneasy Careers and Intimate Lives: Women in Science, 1789-1979* (New Brunswick, NJ: Rutgers University Press, 1987); and Vivian Gornick, *Women in Science: 100 Journeys Into the Territory*, revised ed. (New York, NY: Simon & Schuster/Touchstone, 1990).

However, OTA cautions those who wish to use these projections to predict future supply and demand for researchers. Projections of shortages and surpluses in the Ph.D. s/e work force are notoriously unreliable.[26] As OTA recently concluded:

> The job market for Ph.D.s is unusual. While it responds to demand (in particular, national R&D funding) and to immediate research and training support, the supply is particularly sensitive to Federal policies. As for quality, at the margins talent can be lured or discouraged to relieve shortages and surpluses.[27]

In addition, predicting the demand for academic researchers is extremely complex.[28] As discussed above, such predictions must include demographic changes, immigration trends, anticipated retirements, and the orientations and intentions of new entrants to the research work force, as well as shifting Federal priorities and available research funding. All of these are subject to change, and may

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[26] OTA reached this conclusion on the basis of examining various models of academic and industrial markets. See Office of Technology Assessment, op. cit., footnote 12, especially chs. 3 and 4. Recent independent confirmation of this conclusion comes in a critique of a National Science Foundation model developed by its Policy Research and Analysis Division. See Alan Fechter, "Engineering Shortages and Shortfalls: Myths and Realities," *The Bridge*, vol. 20, fall 1990, pp. 16-20.

[27] Office of Technology Assessment, op. cit., footnote 2, p. 160.

[28] Ted I.K. Youn, "Studies of Academic Markets and Careers: An Historical Review," *Academic Labor Markets and Careers*, David W. Breneman and Ted I.K. Youn (eds.) (Philadelphia, PA: The Falmer Press, 1988), pp. 8-27.

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vary by type of educational institution one attends, the field of Ph.D., the region of the country in which one seeks employment, and so on. Sorting these factors compounds the burdens with which policymakers and educators must cope.

In general, projections also do not take into account market adjustments:

> Most of the simulation models used to assess these labor markets assume . . . that if an imbalance occurs between supply and demand, nothing will occur to correct it. In fact, history demonstrates that these labor markets do tend to equilibrate. Thus, projected imbalances derived from such models—both shortages and surpluses—are always overstatements of what actually will be experienced.[29]

Finally, projections of future retirements and job availability in industry vary to a large extent by field. For instance, some expect faculty shortages to be higher in the humanities and social sciences than in the mathematical and physical sciences, with no shortages foreseen in the biological and behavioral sciences.[30] Also, the health of the pharmaceutical and related industries has a large effect on employment prospects for Ph.D.s in medical and chemical fields. These factors must be taken into account by Federal policies that address projections of shortages. As science policy statesman Harvey Brooks puts it:

> Most projections are based on extrapolations of recent history, usually considering only first derivatives, with little attention to second derivatives, which cannot be accurately estimated anyway. In fact the projection type of exercise has more often than not contributed to the tendency of the technical manpower production system to overreact, building up alternate surpluses and deficits owing to the delayed response of the educational pipeline to the conditions in the market.[31]

Given the uncertainty of projections, OTA finds that concentration on the preparedness of the pipeline to produce Ph.D.s (i.e., increasing the number of undergraduates earning baccalaureates in s/e) is the most flexible policy.[32] If shortages begin to occur in a particular field, prepared undergraduates could be induced by increased graduate support to pursue a Ph.D. in that research area, and Ph.D. production would increase 4 to 7 years later. In addition, those scientists who would have otherwise left the field might stay longer, those who had already left might return, and graduate students in nearby fields could migrate to the field experiencing a shortage.[33] (These are all signals of opportunity sent by the market.)

If shortages do not materialize, then the Nation's work force would be enhanced by the availability of a larger number of highly skilled workers. Research in the United States would also benefit by the training of a larger number of baccalaureates in the sciences, a significant percentage of whom will choose to pursue scientific careers regardless of predictions of shortages, while others contribute their acquired knowledge to other occupations.

Concerns about the demographics of Ph.D. recipients could also be addressed. Laws that prohibit discrimination, such as Title VI of the Civil Rights Act of 1964 and Title IX of the Education Amendments of 1972, justify support to groups defined by the ascribed characteristics of race/ethnicity and sex, respectively.[34] The 1980 reauthorization of the National Science Foundation also created the Science and Technology Equal Opportunities Act (Public Law 96-516). In it, Congress declared:

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[29] Fechter, op. cit., footnote 26, p. 19. Also see Eli Ginzberg, National Research Council, Office of Scientific and Engineering Personnel, "Scientific and Engineering Personnel: Lessons and Policy Directions," *The Impact of Defense Spending in Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986), pp. 25-42.

[30] For the academic administrator perspective, see Elaine El-Khawas, *Campus Trends—1988* (Washington, DC: American Council on Education, 1988); for a different perspective, see William G. Bowen and Julie Ann Sosa, *Prospects for Faculty in the Arts and Sciences* (Princeton, NJ: Princeton University Press, 1989). On the difficulty of applying national projections to regional, institutional, and field-specific academic markets, see Debra Blum, "Many Studies of Future Academic Job Market Are Said To Be of Little Use to Policymakers," *The Chronicle of Higher Education*, vol. 37, No. 23, Feb. 20, 1991, pp. A15, A19.

[31] Harvey Brooks, "Are Scientists Obsolete?," *Science*, vol. 186, Nov. 8, 1974, p. 503. Also see Constance Holden, "Do We Need More Ph.D.s, Or Is Fewer Really Better?" *Science*, vol. 251, Mar. 1, 1991, pp. 1017-1018.

[32] From a market perspective, Ph.D.s are skilled workers who experience low rates of unemployment. However, the Ph.D. worker thinks in terms of career paths. "Underemployment" means that the person is part of the Nation's labor force, but not working in a position that takes full advantage of his or her training and skills. The fit, in short, is not always good.

[33] Recall that 25 percent of scientists are in nonscience and engineering jobs. This is a huge potential reservoir for responding to fluctuations in demand. In general, people with science and engineering training are much easier to convert to other occupations than the reverse.

> . . . that the highest quality science over the long term requires substantial support, from currently available research and education funds, for increased participation in science and technology by women and minorities. The Congress further declares that the impact on women and minorities which is produced by advances in science and technology must be included as essential factors in national and international science, technology, and economic policies.[35]

With reauthorization of the Higher Education Act of 1965 scheduled for the 102d Congress, expectations are high that ''significant and bold changes'' will increase Federal aid to higher education institutions and students, especially historically Black colleges and universities.[36] This legislation empowers Congress and the research agencies that have devised programs targeted to enhance the participation of women and minorities in science to do even more.[37] Programs targeted to minorities, women, the physically disabled, and students in areas of the country where access to research institutions is limited, could help to expand the pool of potential scientists.[38]

Training for an Uncertain Research System

The unity of research and graduate teaching in U.S. higher education has sustained a vigor and creativity in research that is unparalleled in the world. The training of graduate students is also linked to the instruction of undergraduates in s/e. This section first looks at the connection between undergraduate teaching and research and then at the traditional academic research model and some alternatives.

Research and Undergraduate Teaching

Calls for a ''new paradigm'' for higher education in the 21st century are now emanating from the presidents of research universities.[39] Most of these reforms call for improved undergraduate education and ''. . . a better balance between research and teaching.''[40] A related need may also be to change the reward system of the university, since asking universities to augment the teaching of undergraduates may be misplaced if faculty continue to view this as a drain on their time that would be better spent doing research. This tension between the time spent on research and teaching at the major research universities and the use of graduate assistants as instructors for many lower level undergraduate

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[34] Controversy erupted in December 1990 over a Department of Education ruling that ''race-exclusive'' scholarships are discriminatory and should be disallowed. This is seen as an assault on Title VI. Were such a ruling ever upheld, Federal aid and therefore college attendance by minority students could be jeopardized. See Scott Jaschik, ''Scholarships Set Up for Minority Students Are Called Illegal,'' *The Chronicle of Higher Education*, vol. 37, No. 15, Dec. 12, 1990, pp. A1, A20; Kenneth J. Cooper, ''Administration Revises Race-Based Grant Rule,'' *The Washington Post*, Dec. 19, 1990, pp. A1, A8; Ruth Marcus, ''New Scholarship Ruling Caught in Legal Cross-Fire,'' *The Washington Post*, Dec. 18, 1990, p. A8; and Julie A. Miller, ''Alexander Vows to Rescind Policy on Scholarships,'' *Education Week*, Feb. 13, 1991, pp. 25, 28.

[35] National Science Foundation Authorization and Science and Technology Equal Opportunities Act, Dec. 12, 1980, 94 Stat. 3011.

[36] See Thomas J. DeLoughry, ''Colleges Welcome News That Rep. Ford Will Chair House Postsecondary Education Subcommittee,'' *The Chronicle of Higher Education*, vol. 37, No. 12, Nov. 21, 1990, p. A23.

[37] Office of Technology Assessment, op. cit., footnote 15, app. B.

[38] It is clear that market forces alone will not increase the participation of women, minorities, and the physically disabled in science and engineering. Policy intervention is required. Therefore, there is no inconsistency between letting the market operate for some segments of the student population while targeting other segments through recruitment and retention programs. For examples, see Linda Dix (ed.), *Minorities: Their Underrepresentation and Career Differentials in Science and Engineering*, workshop proceedings, National Research Council (Washington, DC: National Academy Press, 1987); and Cynthia Lollar, ''Access to Engineering: New Project for Students and Faculty With Disabilities,'' *Science*, vol. 251, Feb. 22, 1991, p. 952.

[39] Prominent among them are the two institutions that OTA studied as case examples, Stanford University and University of Michigan. See Karen Grassmuck, ''Some Research Universities Contemplate Sweeping Changes, Ranging From Management and Tenure to Teaching Methods,'' *The Chronicle of Higher Education*, vol. 37, No. 2, Sept. 12, 1990, pp. A1, A29-31. Stanford's reforms include various programs, most funded by a $5 million gift to the university, ''. . . designed to give faculty members ranging from graduate teaching assistants to senior professors better incentives to concentrate on effective instruction.'' See Kenneth J. Cooper, ''Stanford President Sets Initiative on Teaching,'' *The Washington Post*, Mar. 3, 1991, p. A12.

[40] Grassmuck, op. cit., footnote 39, p. A29. Also see Courtney Leatherman, ''Definition of Faculty Scholarship Must Be Expanded to Include Teaching, Carnegie Foundation Says,'' *The Chronicle of Higher Education*, vol. 37, No. 14, Dec. 5, 1990, pp. A1, A16-A17; and Alliance for Undergraduate Education, *The Freshman Year in Science and Engineering: Old Problems, New Perspectives for Research Universities* (University Park, PA: 1990).

Photo credit: Bob Kalmbach

Students at the University of Michigan walk on campus between classes. Undergraduate teaching is an important part of faculty responsibilities.

classes has caused some to question the health of undergraduate teaching at these universities.[41]

Another concern that stems from the tension between research and teaching is the relation between providing more funds for basic research and improving both the institution's research performance and teaching capability. A common perception during the 1960s was that Federal dollars that supported research also benefited undergraduate teaching because these top researchers would communicate their excitement about developments "at the laboratory bench" to undergraduate and graduate students alike. In the 1980s, with the separation between research and undergraduate education becoming more pronounced at many research institutions (particularly with many faculty "buying out" of teaching responsibilities when awarded a large research grant), the connection between research progress and the cultivation of human resources grew more tenuous.[42]

Consequently, many research agencies see a larger need for funding undergraduate teaching directly. In addition, many faculty have proposed novel ideas. For example:

> What if the four-year colleges . . . began requiring the university departments whose doctoral students apply for jobs at the four-year colleges to provide a detailed description of how they had prepared those candidates to teach, as well as specific evaluations of their teaching skills? . . . Granted, the most selective graduate departments at the top research universities—those that aspire chiefly to staff the faculties of other prestigious universities—might not be especially responsive. . . . Although institutions routinely "raid" each other for distinguished researchers, they hardly ever pursue outstanding teachers so aggressively. As long as that disparity exists, talented teachers will be captives of their current employers, with little leverage to extract greater rewards.[43]

Indeed, growth in the employment of Ph.D.s by 4-year institutions has been hearty for over a decade.[44]

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[41] Of particular concern is its effect on the recruitment of new baccalaureates, since they may have to wait until their sophomore or junior year until they are taught primarily by faculty. The utilization of graduate students for teaching posts, however, can be quite valuable from the graduate student's prospective, since these classes may represent one of the few opportunities to teach (though not necessarily *learn how* to teach). In 1990, the Howard Hughes Medical Institute announced a $30 million grant competition to strengthen undergraduate science education. Ninety-nine institutions, many of them liberal arts colleges, will compete for 5-year grants ranging from $500,000 to $2 million. Winners will be chosen on the basis of proven success: the proportion and number of graduates who, over the past decade, have gone on to medical school or to earn doctorates in biology, chemistry, physics, or mathematics. For background, see Liz McMillen, "Hughes Institute Awards $61 Million for Science Education," *The Chronicle of Higher Education*, vol. 35, No. 38, May 31, 1989, pp. A19-A20; and Linda Marsa, "Howard Hughes Medical Institute Enriches Undergrad Science Studies," *The Scientist*, vol. 5, No. 1, Jan. 7, 1991, pp. 28-29.

[42] See Anthony B. Maddox and Renee P. Smith-Maddox, "Developing Graduate School Awareness for Engineering and Science: A Model," *Journal of Negro Education*, vol. 59, 1990, pp. 479-490. This connection has also arisen over requiring institutions of higher education receiving Federal assistance to provide certain information on graduation rates, broken down by program and field of study. See Public Law 101-542, Title I—Student Right-To-Know, 101st Cong., Nov. 8, 1990, 104 Stat. 2381-2384.

[43] Teaching reputations are local, while research reputations are global. This applies even to prospective students. The best students tend to flock to institutions where faculty have the greatest external reputations. Richard Chait, "The Pro-Teaching Movement Should Try Economic Pressures," *The Chronicle of Higher Education*, vol. 36, No. 43, July 11, 1990, p. A36.

[44] From 1975 to 1987, percentage increases in the employment of Ph.D. scientists and engineers in 4-year institutions ranged from 15 percent in mathematics to over 200 percent in computer science (albeit from a small base number in this field). Most fields increased by 25 to 50 percent. For a discussion of these trends (based on National Science Foundation (NSF) data), see Commission on Professionals in Science and Technology, op. cit., footnote 5, pp. 18-19. The role of research at these traditionally *teaching* institutions is also cause for concern. In fiscal year 1988, of 21,000 research proposals submitted to NSF for funding, 12 percent came from investigators at "predominantly undergraduate institutions" and 8 percent of all awards were made to these investigators, accounting for 5 percent of NSF funds awarded competitively that year. See National Science Foundation, *FY 1988 Research Proposal and Award Activities by Predominantly Undergraduate Institutions*, NSF 90-36 (Washington, DC: March 1990), p. 3. Also see Linda E. Parker and David L. Clark, "Research at Liberal Arts Colleges: Is More Really Better?" *Research Management Review*, vol. 3, spring 1989, pp. 43-55.

These calls for increased undergraduate teaching by faculty seek to alter an academic research and teaching model in the United States that may already be under strain. What follows is an examination of the academic research model and its contribution to human resources at the Ph.D. level.

The Academic Research Model

The predominant mode of academic research in the natural sciences and engineering begins with a research group that includes a principal investigator (most often a faculty member), a number of graduate students, one or several postdoctoral scientists, technicians, and perhaps an additional nonfaculty Ph.D. researcher. While this group may be working on a single problem funded by one or two grants, subsets of the group may work on different but related problems funded simultaneously by multiple project grants. (In the social sciences, the groups tend to be smaller, often numbering only the faculty member and one to two graduate students.)[45] The "young investigator" problem must thus be seen in the broader context of other changes in the university as a research training site.

During graduate study, along with self-teaching and learning from one's peers, much of what is learned comes directly through mentorship by professors, postdoctoral fellows, or nonfaculty researchers. In many research universities, professors are responsible for multiple graduate students at any given time, so that in a professor's career he or she may train over 20 (sometimes many more) Ph.D.s. As one observer commented:

> Simple arithmetic shows that training in a top laboratory at a top institution, combined with the requisite number of high-quality publications, does not by itself ensure anyone a position similar to that of his or her mentor. Most top laboratories graduate two or three postdoctoral fellows a year. . . . Multiply that by the large number of top laboratories in the country, and it becomes clear that even in good times not all these young investigators and their research programs can be absorbed into the National Institutes of Health system.[46]

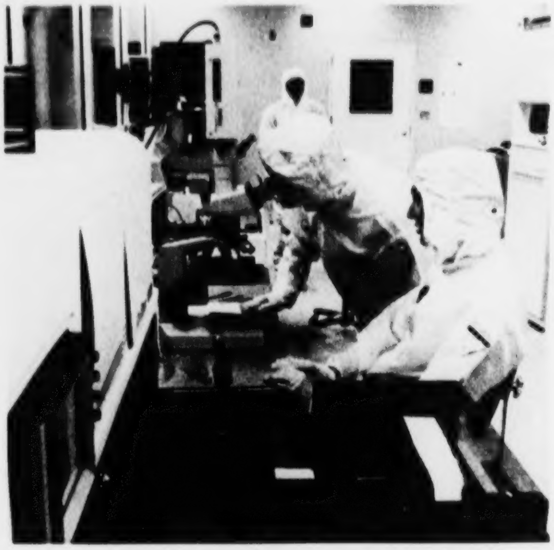

Photo credit: Chuck Painter, News and Publications Service, Stanford University

Graduate students work in the Center for Integrated Studies at Stanford University. Research and teaching go hand-in-hand in much of graduate training.

In addition, the dominant model to launch a career as a young scientist is movement from one research university to another with an assistant professorship, the attainment of a first Federal research grant, and the re-creation of the mentor's professional lifestyle (i.e., independent laboratory, graduate students, postdoctorates). For an institution to subscribe to this model, unfortunately shifts much responsibility for awarding tenure from the department faculty to the Federal Government. While university officials say there is ". . . no fixed time in which researchers are expected to become self-sufficient through outside grants . . . researchers who have failed to

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[45] The exploitation of competent graduate students has been a perennial charge—some mentors keep them around as long as possible because they are talented cheap labor. Competition for tenure-track positions requires refereed publications on the resume of the new Ph.D. This, too, may prolong the graduate research career. Registered time to the doctorate increased from 1967 to 1986, yet a recent National Research Council study suggests that the reasons for this increase cannot be readily deciphered. According to one observer, the recent leveling off of this trend in time to Ph.D. may reflect ". . . changes in the job market for new Ph.D. recipients. It will be interesting . . . to see if the numbers fall—as market-oriented theories would predict—when the expected increase in demand for faculty begins later in the 1990s." See National Research Council, *On Time to the Doctorate: A Study of the Increased Time to Complete Doctorates in Science and Engineering* (Washington, DC: National Academy Press, 1990); Peter Syverson, "NRC Releases New Study on Increased Time to the Doctorate," *CGS Communicator*, vol. 23, August 1990, p. 8; and Paul Gassman, "Shortening the Time to a Ph.D.," *Chemical & Engineering News*, vol. 68, No. 52, Dec. 24, 1990, pp. 25-26.

[46] Dinah K. Bodkin, "Young Scientists and the Future," letter, *Science*, vol. 249, Sept. 28, 1990, pp. 1485-1486. Of course, some of these Ph.D.s will neither pursue an academic career nor compete for National Institutes of Health funds. The situation is less predictable than the author's extrapolation suggests.

Box 7-C—Point of View of a "Small" Scientist

The following are verbatim excerpts from a recent "Point of View" column titled: "We Need To Give a Chance to Small, Unfashionable Science," published in *The Chronicle of Higher Education.*[1]

> While literally millions of dollars are being spent on massive, equipment-rich projects, other 'small' sciences are in real danger of drowning for lack of funds. . . . Although I've received 22 grants from the National Science Foundation and a host of private foundations during the last 15 years, grant money is now much harder to get. Support for anthropology has gone from modest to minuscule.
>
> "There's no real problem," I used to think while responding sympathetically to my peers' groans over another rejected grant. "Good science will always get funded." I learned this magic formula from my mentors while I was in graduate school and thought that if I repeated it often enough and believed it devoutly enough, I would be protected from disaster. But plenty of good science is not receiving support these days. . . .
>
> "The long-term trends are grim. In the last 10 years, the number of grant applications submitted annually to the National Science Foundation's anthropology program has risen, as have the indirect costs of research. But the total budget for the program has remained approximately constant in real dollars. Consequently, the percentage of applications receiving support has dropped. For example, 32 per cent of the applications submitted for archaeology research in 1980 were approved, compared with only 23 per cent in fiscal 1990. What's more, the average dollar amount of the grants has dwindled during a period when virtually all the costs of actually conducting research have risen. John Yellen, director of the foundation's anthropology program, said recently with a sigh: "What seemed a large but reasonable grant for us to fund 10 years ago now looks out of sight". . . .
>
> "I do not know where the next generation of field researchers will come from, because the odds against starting up a major project are so great now. I do know that without field researchers, anthropology will stagnate into a family feud and eventually will perish from sheer triviality. . . .
>
> "Some deliciously subtle ways exist for a reviewer to sabotage a grant proposal, thereby blocking or stalling a particular line of research. They range from simply giving a vaguely lukewarm review, to claiming falsely that the applicant has overlooked important work in the field, to planting poisonous questions about methodology that the review panel will then assume have not been addressed in the proposal. The temptation to engage in such unethical behavior is greater if everyone is feeling the pinch. . . . Under these conditions, the review process becomes one of paring down the proposals to a manageable number for ranking, rather than deciding how many are good enough to receive support. . . .
>
> "The dilemma for program directors is: With too little money to go around, should they spread it around like food supplies in a famine, giving everyone enough for a taste but not enough to maintain health? Or should they support fewer projects more fully, condemning others to oblivion?
>
> "I would love to see a box printed on federal income tax forms saying, "Check here if you want one dollar of your return to go to support basic science research." Another solution is to guard against spending all of our money for megabucks projects with catchy titles that appeal to legislators. Small, unfashionable science, as well as big, sexy science, is important. Sometimes great ideas and staggering discoveries come from the little guys with funny ideas, pottering away in the corner by themselves. We need to give them a chance. . . . "

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[1] The author is Pat Shipman; the column appeared Sept. 26, 1990, p. A60. For another expression of related values, see Eugene Garfield, "Fast Science vs. Slow Science, Or Slow and Steady Wins the Race," *The Scientist*, vol. 4, No. 18, Sept. 17, 1990, p. 14.

win such grants are less likely to earn tenure than their colleagues who have found such support."[47] In many fields, young Ph.D.s and older ones as well are living out this scenario (see box 7-C).

As seen in the preceding chapter, most universities cannot afford to defray faculty research costs for very long, and the cost of supporting students has in part been transferred to the research budget.[48] The

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[47] See Debra E. Blum, "Younger Scientists Feel Big Pressure in Battle for Grants," *The Chronicle of Higher Education*, vol. 37, No. 4, Sept. 26, 1990, p. A16. As one researcher put it: "Leading universities should make their own decisions about who their faculty are going to be, and not leave it to the study sections of NIH." Quoted in David Wheeler, "Biomedical Researchers Seek New Sources of Aid for Young Scientists," *The Chronicle of Higher Education*, vol. 36, No. 42, July 5, 1990, p. A23.

[48] Research assistantships experienced the greatest increase as the support mechanism for science and engineering students from 1980 to 1988. See National Science Board, op. cit., footnote 4, figure 2-11, p. 58.

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combined costs of set-up and operation alone (which for the typical chemistry or biomedical laboratory is on the order of $200,000 to $400,000)[49] have ballooned. The priority of this academic, individual investigator-based research model has become increasingly difficult for some institutions, fields, departments, and faculty mentors to maintain.

The Federal research system is presently trying to cope with growing demand for research monies, as measured by proposals submitted to the research agencies.[50] A potential shift of members of the research work force out of universities and into another sector, or into academic work that is not research-centered, can be recognized as normal labor market adjustment. Such movement would testify to the versatility and adaptability of Ph.D. researchers and to the Nation's ability to utilize their talents.[51]

Computer science is just such a case example. About 800 new Ph.D.s in this field are granted annually in North America, double that of a decade ago. The demand for new faculty has slowed, new departments are not being created, and existing departments are not expanding. Industrial and government computer research leaders asked:

> . . . whether the current situation warranted concern (i.e., is there a Ph.D. surplus, or are the supply and demand levels reasonably in balance). Reports of graduating Ph.D.s not finding the kind of academic positions they desired . . . [lead to] the suggestion that the expectations of these graduates need to be adjusted. Not every bright, new Ph.D. will find an academic position in a top-tier research university. Postdoctoral positions in computer science are becoming more common, and . . . graduates will need to look toward second-tier research universities as well as four-year colleges in order to fulfill their career objectives.[52]

There is doubtless a role for universities to play in the diversification of research careers of recent Ph.D.s.[53] New Ph.D.s find it difficult to entertain alternative opportunities if they have no experience with them. Thus, programs that offer a summer in a corporate laboratory or part of an academic year at a liberal arts college can help advanced graduate students visualize working in settings other than the university. Arrangements that link a historically Black college or university or liberal arts college to a research university or national laboratory stretch the resources and experience of both participating institutions.[54]

If the career prospects that new Ph.D.s confront are so different from what they were taught to expect and value, there can be a crisis of confidence. As one university administrator states:

> We are giving out mixed signals. Universities are competing intensely with one another to hire the best young Ph.D.s. On the other hand, the positions (at least in many fields of science) available to the average but quite capable Ph.D. are not very attractive. Moreover, many very good students are turned off when they see what the young faculty are up against.[55]

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[49] One report on set-up costs in chemistry at the University of Minnesota shows fourfold increases from 1979-80 to 1989-90. See Paul G. Gassman, "Future Supply and Demand in Academic Institutions," *Human Resources in Science and Technology: Improving U.S. Competitiveness*, Proceedings of a Policy Symposium for Government, Academia, and Industry, Mar. 15-16, 1990, Washington, DC, Betty Vetter and Eleanor Babco (eds.) (Washington, DC: Commission on Professionals in Science and Technology, 1990), pp. 35-36.

[50] See U.S. Congress, Office of Technology Assessment, "Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System," staff paper of the Science, Education, and Transportation Program, April 1990.

[51] For a discussion, see National Research Council, Office of Scientific and Engineering Personnel, *Fostering Flexibility in the Engineering Work Force* (Washington, DC: National Academy Press, 1990). Among the National Research Council conclusions are: a) that the production of adaptable engineers is impeded not by the engineering curriculum, but how that curriculum is delivered; and b) that continuing education could enhance adaptability in the engineering work force.

[52] John R. White, "President's Letter: Reflections on Snowbird," *Communications of the ACM*, vol. 33, September 1990, p. 19.

[53] Better faculty advising of graduate students is an obvious need. See Carolyn J. Mooney, "The Dissertation Is Still a Valuable Requirement, Survey Finds, But Graduate Students Say They Need Better Faculty Advising," *The Chronicle of Higher Education*, vol. 37, No. 18, Jan. 16, 1991, pp. A15, A22; and Association of American Universities, *Institutional Policies to Improve Doctoral Education* (Washington, DC: November 1990).

[54] To date, such arrangements have been most common in undergraduate engineering. One coalition, spearheaded by a 5-year, $15 million National Science Foundation grant, will establish a communications network for information dissemination, faculty exchange, workshops, and outreach to elementary, secondary, and community college students. The participating universities are City College of New York, Howard, Maryland, Massachusetts Institute of Technology, Morgan State, Pennsylvania State, and Washington. See "NSF Announces Multi-Million Dollar Grants To Form Engineering Education Coalitions," *NSF News*, Oct. 9, 1990. Also see Oak Ridge Associated Universities, *1990 Annual Report* (Oak Ridge, TN: 1990). Oak Ridge Associated Universities is a Department of Energy laboratory and a consortium of 59 colleges and universities engaged in research and educational programs in the areas of energy, health, and the environment.

[55] Neal Lane, "Educational Challenges and Opportunities," Vetter and Babco, op. cit., footnote 49, p. 94.

Universities are caught between the desire to train the next generation and the harsh reality that their research apprentices may face a different form of competition for resources (for a controversial example, see box 7-D).

New Models

The National Science Foundation recently announced that the 20 research universities that receive the most NSF support "... will work together to improve science and mathematics education in schools and to increase the number of women and minority students and faculty members in science and engineering." Actions include changing tenure policies to reflect the extra family responsibilities often carried out by women and encouraging faculty to work with schoolchildren and teachers.[56]

Other models of education could be encouraged that feature a greater sharing of resources (e.g., equipment and space) and people (e.g., doctoral students, nonfaculty researchers, and technicians). Models that stress research in units other than academic departments, research in *nonacademic* sectors, and *nonresearch* roles in academia could be entertained. These models are already being applied in the centers programs sponsored by NSF. Centers, which support individual researchers (as faculty and mentors) as well, may represent a new way of doing business for NSF and the companies that participate in them.[57]

In the 1980s, centers at NSF became the focus of political dispute.[58] At issue was the appropriateness of promoting such a mode of research organization in view of the basic research and science education missions of NSF. For NSF, however, the centers complete "... a balanced portfolio of individual investigator grants, facilities, and center activities."[59] Engineering Research Centers (ERCs) were intended to foster university-industry collaborations. As a 1988 General Accounting Office study found, participating companies "... expect to benefit over time through better personnel recruiting ... [even though] it is too early to determine the program's impact on engineering education."[60]

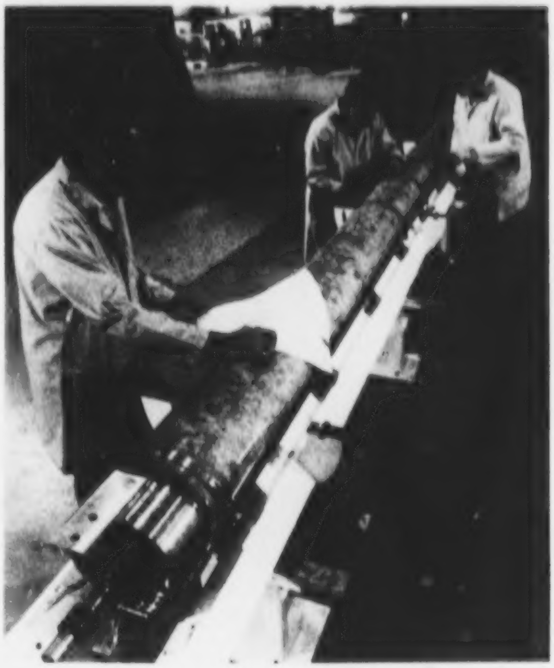

Photo credit: U.S. Department of Energy

Three scientists work on a magnet for the Superconducting Super Collider. Teamwork is an important part of research groups.

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[56] See "NSF, Universities Plan for Women, Minorities," *The Chronicle of Higher Education*, vol. 37, No. 1, Sept. 5, 1990, p. A2. Incorporating incentives for affirmative action into programs that allocate research dollars underscores the importance of human resources as a criterion for Federal research funding. It remains to be seen whether universities respond—with or without prodding by the National Science Foundation.

[57] In 1990, the National Science Foundation (NSF) supported 19 Engineering Research Centers and 11 Science and Technology Research Centers (STCs) at $48 million and $27 million, respectively. Thus, together they account for less than 10 percent of NSF's budget, while providing a long-term funding base (5 to 11 years) for interdisciplinary and high-risk projects oriented to the applied, development, and commercial-use end of the research continuum. See Joseph Palca and Eliot Marshall, "Bloch Leaves NSF in Mainstream," *Science*, vol. 249, Aug. 24, 1990, p. 850. In the block-grant, multi-investigator approach embodied by STCs, "NSF has rolled the dice on an experiment in science, and it will take some time to know whether it has come up with a winner." See Joseph Palca, "NSF Centers Rise Above the Storm," *Science*, vol. 251, Jan. 4, 1991, pp. 19-22, quote from p. 22. Also see Jeffrey Mervis, "NSF Cuts Back on Faltering Science, Technology Centers," *The Scientist*, vol. 5, No. 3, Feb. 4, 1991, pp. 1, 4, 24.

[58] See Robert L. Park, "The Next Leader of the National Science Foundation Must Press for a Greater U.S. Investment in Science," *The Chronicle of Higher Education*, vol. 36, No. 48, Aug. 15, 1990, p. B3.

[59] John A. White, "Disputing Some Claims About the NSF," *The Chronicle of Higher Education*, vol. 37, No. 3, Sept. 19, 1990, p. B4.

[60] The General Accounting Office adds that "... although cross-disciplinary and joint research are the goals of the ERC program, industry participants believe that the quality and type of research are more important reasons for sponsoring ERCs." See U.S. General Accounting Office, *Engineering Research Centers: NSF Program Management and Industry Sponsorship*, GAO/RCED-88-177 (Washington, DC: August 1988), pp. 2-3.

Box 7-D—The Priority of Research Training

In November 1990, the Institute of Medicine (IOM) published a report on priorities in health sciences:

> The charge to the committee was to analyze the funding sources for research projects, training, facilities, and equipment by Federal and nonfederal sources. The committee was asked as well to develop a coordinated set of funding policies to restore balance among these components of the research enterprise in order to ensure optimal use of research dollars. . . . The goal of the study was to ensure that, at any given level of support, allocation policies would enable the scientific community to utilize available resources in the most efficient manner so as to create an optimal research environment and achieve society's goals for research into human disease.[1]

First, by adopting "imbalance" as a premise and then by concluding that if the National Institutes of Health budget were not to grow over inflation in the coming decade (one of four funding scenarios considered by the IOM committee), expenditures for research training and facilities should take priority. The report rankled the biomedical research community. Leading the dissent was the Federation of American Societies for Experimental Biology (FASEB), which objects to any diversion of funds at the expense of individual investigators.[2]

FASEB rejected the premise of the IOM report that in an era of tight budgets, biomedical funds should be balanced. FASEB claimed there is no imbalance, arguing that increased funds for training and construction will jeopardize ". . . productivity in the foreseeable future." FASEB president Thomas Edgington, an immunology professor at the Research Institute of Scripps Clinic, California, feared that implementation of the IOM recommendations would ". . . diminish advances of value to the public." He continued: "We advocate . . . a total increase of support of the enterprise as a whole." So while committee chairman Bloom insisted: "We're eating our seed corn," Edgington concluded: "Training has not decreased." Chemist Ronald Breslow, a member of the IOM committee, added another point on the training issue:

> Supporting training through research grants ties training too much to the success of the research advisor. Giving money to the student rather than the sponsor changes their relationship. Trainees can then work on their own projects rather than being a sort of employee. It's more encouraging to the student to be told "You are a winner" rather than "Just go beg for support."[3]

This public dispute highlights several points. First, it attests to the depth of anxiety that grips investigators in search of stable, multiyear research funding. Second, by entertaining a "no real growth" funding scenario, the IOM report puts into black-and-white what few investigators want to contemplate, i.e., tight funding could get tighter. Third, by favoring an increase of research training funds under the worst-case scenario, the committee removed research funds as the first priority. Indeed, "The committee believes that this growth in the training budget will not enlarge the research project grant applicant pool; rather, the net effect of this gradual reallocation will be to replace the increasing number of scientists expected to retire later this decade."[4]

This IOM report should be applauded for attempting to make forecasts and preparing for its consequences by systematically considering priorities among resources. However, the conclusion to increase training funds is problematic.[5] At present the system is producing an abundance of new Ph.D.s in biomedical fields. Enhancing this production while holding the line on the research grants that must support them is rightly open to question. Nevertheless, policymakers will welcome the IOM report for its look at a hard, complex problem and its statement of priorities.

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[1] Institute of Medicine, Committee on Policies for Allocating Health Sciences Research Funds, *Funding Health Sciences Research: A Strategy to Restore Balance*, F.E. Bloom and M.A. Randolph (eds.) (Washington, DC: National Academy Press, 1990), p. 5.

[2] The Federation of American Societies for Experimental Biology criticism was reported almost simultaneously by: Barbara J. Culliton, "FASEB 'Rejects' IOM Study," *Science*, vol. 250, Nov. 30, 1990, p. 1199; "Strife Erupts Over Shares of Biomedical Funding," *Science & Government Report*, vol. 20, No. 19, Dec. 1, 1990, pp. 1-4; and Pamela Zurer, "Biomedical Research: Calls for Shifts in Funding Attacked," *Chemical & Engineering News*, vol. 68, No. 49, Dec. 3, 1990, p. 6. Material quoted below comes from one or all of these sources.

[3] Also see Ronald Breslow, "Funding Science Research," letter, *Chemical & Engineering News*, vol. 68, No. 51, Dec. 17, 1990, p. 2.

[4] See Institute of Medicine, op. cit., footnote 1, p. 8. Also see National Research Council, *Biomedical and Behavioral Research Scientists: Their Training and Supply* (Washington, DC: National Academy Press, 1989).

[5] Edgington also assailed the makeup of the IOM committee, saying that it was composed mostly of research administrators and had few working scientists.

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Table 7-1—Issues in Team Research Performed in Different Organizational Contexts

Key issues	Small, university based	Large, university based (organized research unit)	Small, industry based	Large, industry based
Number of disciplines involved	Small	Moderate	Moderate	Moderate to large
Typical research	Pure	Pure-applied	Applied-pure	Applied and pure-applied
Funding	Short term and uncertain	Relatively certain	By contract and short term	Relatively certain
Source of research problems to be solved	Found by team	Found by team (largely)	Given by environment	Found by team and given by environment
Structure of organization	Flat	Hierarchical (selective decentralization)	Flat	Hierarchical (selective decentralization)
Leader's involvement	Part time	Full time	Part time	Full time
Member's career prospects	Uncertain	Relatively certain/ predictable	Uncertain	Relatively certain/ predictable
Key leadership roles	Outside liaison	Outside liaison and coordination	Outside liaison and resource acquisition	Motivation and management of different teams
Communication problems	Few potentially	Internal and external	External	Internal
Access to scientific and technical resources	Good	Good	Not so good	Good if affordable

SOURCE: Adapted from Julie Thompson Klein, *Interdisciplinarity: History, Theory, and Practice* (Detroit, MI: Wayne State University Press, 1990), table 1, p. 124.

Research in general is becoming increasingly interdisciplinary, i.e., it requires the meshing of different specializations to advance a research area.[61] Academic departments house specialists by discipline whose research will be performed in units—centers, institutes, programs—that cut across the traditional departmental organization on campus. Such organized research units (ORUs) have a history on U.S. university campuses, but not as a dominant structure.[62] Klein writes:

> In the 1960s Federal legislation gave birth to several kinds of ORUs, including NASA space centers, water resource centers, and later, regional education laboratories. A number of ORUs are *de facto* independent of the university that gave birth to them, and Caltech's Jet Propulsion Laboratory is even larger than its ''nominal parent,'' Caltech.[63]

Team research, whether interdisciplinary or not, takes place in many organizational contexts, subject to various influences[64] (for a summary, see table 7-1). While the disciplinary department still prevails, a wide range of organizational models are now employed by universities to manage and conduct research. The autonomy, formality, and permanence of these production units depend on adapting the demands of outside patronage to local custom and need, including the support and on-the-job research training of graduate students.

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[61] For example, see A.L. Porter and D.E. Chubin, ''An Indicator of Cross-Disciplinary Research,'' *Scientometrics*, vol. 8, 1985, pp. 161-176; and Don E. Kash, ''Crossing the Boundaries of Disciplines,'' *Engineering Education*, vol. 78, No. 10, November 1988, pp. 93-98.

[62] D.I. Phillips and B.P.S. Shen (eds.), *Research in the Age of the Steady-State University* (Boulder, CO: Westview Press, 1982). Three models of organized research units (which are common in industry and the Federal laboratories) have taken root on campus—agricultural experiment stations, water resources research centers, and engineering research centers. See Robert S. Friedman and Renee C. Friedman, ''Science American Style: Three Cases in Academe,'' *Policy Studies Journal*, vol. 17, No. 1, fall 1988, pp. 43-61. Several other models could be mentioned; e.g., the Joint Center for Laboratory Astrophysics at the University of Colorado, the Center for Astrophysics (the Smithsonian Astrophysical Observatory-Harvard Astronomy Department Partnership), and the Materials Research Laboratories (supported by the National Science Foundation).

[63] Julie Thompson Klein, *Interdisciplinarity: History, Theory, and Practice* (Detroit, MI: Wayne State University Press, 1990), p. 123.

[64] See Donald Pelz and Frank D. Andrews, *Scientists in Organizations: Productive Climates for Research and Development*, revised ed. (Ann Arbor, MI: University of Michigan, Institute for Social Research, 1976).

Box 7-E—Flexibility at the Beckman Institute

The Beckman Institute for Advanced Science and Technology is located on the University of Illinois Urbana-Champaign campus and was built with a 1985 donation of $40 million from Arnold and Mabel Beckman. In the words of its director, Theodore L. Brown, the mission of the institute is "... to advance the life and behavioral sciences, physical sciences, and engineering through promotion of multidisciplinary and interdisciplinary research of the highest quality," in particular "... to transcend the limitations of departmental structure."[1] Over 700 faculty, postdoctoral associates, graduate students, and others work full- or part-time at the institute.

The institute divides its research programs into nine multidisciplinary groups. For example, one group includes faculty in neuronal pattern analysis, cognitive neuroscience, perception, biomechanics, and molecular biology. It addresses a range of problems from the molecular level to cognitive science.[2] Perhaps most well known of the nine groups is the National Center for Supercomputing Analysis, which performs research in the diverse use and analysis of supercomputer-generated models.

To maintain flexibility in its research missions and yet provide some measure of security for the faculty, the Beckman Institute has taken advantage of its position outside of the university departments and developed a "rolling appointment" system:[3]

- **Roughly 35 faculty call the Beckman Institute their full-time research home, although each retains a departmental affiliation. Faculty have 5-year appointments, which are extended every year, as long as their research is productive for the institute. If the appointment is not extended, then the faculty member has 5 years in which to move back to his or her department (where their tenure is based).**
- **Another 90 to 100 faculty members are part time at the institute, and are based primarily in their departmental homes. Each has a 3-year appointment, which is renewed like appointments of full-time faculty.**
- **Space is allocated in the institute only for those who use it, and is taken away if insufficiently occupied.**

So far the system has worked well for the faculty at the institute; it represents a novel attempt to maintain flexibility in the university environment. In the future, other institutes and centers may view the Beckman Institute as a model.

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[1] See Ward Worthy, "New Beckman Institute Promotes Broad-Ranging Research Effort," *Chemical & Engineering News*, vol. 68, No. 34, Aug. 20, 1990, pp. 23-24.

[2] Ibid., p. 23.

[3] Ibid., p. 24.

With the ascendance of what OTA called in the last chapter the "industrial model" of research, changes in the units producing knowledge have become apparent.[65] One could predict that university investigators will gravitate to those units that bring together the needed personnel and instrumentation, and ease the research process, especially if Federal and other sources of support favor centers as efficient sites of research performance (see box 7-E). Does it matter that research laboratories in an academic department come to resemble an ORU—be it an ERC, a supercomputer center, or another campus-wide institute that is largely federally funded?[66] One physicist writes:

> Goal-oriented research and a traditional belief in team methods favor large, centralized approaches in many industrial and Federal laboratories. (Small groups can also flourish in these environments—the two discoverers of high-temperature superconductivity are industrial scientists.) . . . For the same reasons that artists use different environments or new media to stimulate creativity, scientists need different ways to do science. This will help ensure

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[65] Science policy statesman John Ziman claims that science is "... being 'collectivized' in two different senses of the word. On the one hand, almost all research nowadays is being carried out within the framework of quite large organizations ... In many cases, research projects are undertaken by groups or teams of researchers who have limited control over the resources they use, and cannot claim personal responsibility for what is attempted or what is achieved. In other words, the extreme *individualism* embodied in the academic ethos ... is no longer consistent with the realities of scientific life, where *collective* action is now the rule. ... On the other hand, the incorporation of academic science into an expanding 'R&D' system, drawing funds from the central government and private industry ... [means] academic science is losing its place as an autonomous social segment with its own standards and goals, and is being brought under 'collective' control. Instead of being treated as an independent source of unpredictable social influences, it has come to be regarded as an instrument of deliberate societal action." See John Ziman, "Collectivized Science," *An Introduction to Science Studies* (Cambridge, England: Cambridge University Press, 1984), pp. 132-139, quote from pp. 138-139.

[66] See National Research Council, *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987).

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> that research careers attract good minds of every sort—those that flourish in isolation, and those that thrive on interaction.[67]

The trend toward larger research teams, more cooperation among individuals and groups, and more multiauthored papers is unmistakable.[68] The question is whether large research groups will effectively duplicate or augment the mentorship function. Whatever the campus research setting, it must be valuable for the socialization of new Ph.D.s. The *process* of scientific research is learned in university settings, but sometimes the skills associated with the process (e.g., data handling and communication practices) do not transfer well to nonacademic settings.[69]

Other Considerations

Federal research funding serves various goals, none more important than the strengthening of education and human resources. The Federal Government has a special role both as a primary catalyst of the future supply of Ph.D.s and as one employer of the existing Ph.D. work force.[70]

In addition to the issues outlined above, the Federal Government must also consider several questions. First, given the tendency of Federal funding to concentrate in a small set of universities, what efforts should be made to support other institutions? (Or is there an optimal mix?) Twenty percent of all authors of scientific papers produce 80 percent of the scientific literature.[71] Furthermore, basic researchers are concentrated in a relatively small subset of all academic institutions, and conventional wisdom says that scientific productivity depends on the extraordinary achievements of relatively few researchers, laboratories, and universities.[72] Writing in 1968 as a physicist and academic dean, as well as a policy advisor, Harvey Brooks put it this way:

> The vigor of a scientific field seems to depend on a continuing injection of new investigators with fresh ideas and on sufficient funds to exploit new ideas. . . . To spread the same funds more and more thinly over a growing number of investigators, institutions, and students would be a prescription for the slow strangulation of science in the United States.[73]

To avert the "slow strangulation of science," a concentration of funding in select research institutions and research groups (which is what the Federal Government currently practices) would seem wise. However, at what point does concentration begin to disrupt the interdependence among researchers? Not funding a wide array of researchers risks curbing more than the flow of resources; it can interrupt the flow of communications and begin to deter cooperation between specialists. Such cooperation, which contributes to the accumulation of research findings, is especially intense at universities.[74] Sustaining productive researchers (and the students who will eventually join the top ranks of scientists and engineers) fuses Federal research funding policy with training, employment, and productivity concerns.

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[67] Sidney Perkowitz, "Larger Machines Are Breeding Larger Research Teams," *The Scientist*, vol. 3, Oct. 16, 1989, pp. 13, 15.

[68] National Science Board, op. cit., footnote 4, p. 120.

[69] For a discussion, see National Academy of Sciences, Committee on the Conduct of Science, *On Being A Scientist* (Washington, DC: National Academy Press, 1989), pp. 10-22. Also see Terry Shinn, "Scientific Disciplines and Organizational Specificity: The Social and Cognitive Configuration of Laboratory Activities," *Scientific Establishments and Hierarchies*, N. Elias et al. (eds.) (Dordrecht, Holland: D. Reidel, 1982), pp. 239-264.

[70] The Federal Government employs 200,000 scientists and engineers, about 11 percent of the Federal work force. And although many of these people neither have a Ph.D. nor do bench research, they are facilitators of research performance (as agency program managers). Micromanagement of the Federal laboratories, personnel ceilings, noncompetitive salary, inadequate fringe benefits, ethics laws, and the public image of Federal service are reported to contribute potentially to a Federal "brain drain." Yet only 5 percent leave Federal employment annually. See Janice Long, "Agencies Compete Well in Science Job Market," *Chemical & Engineering News*, vol. 68, No. 39, Sept. 24, 1990, p. 23. For further discussion, see Alan K. Campbell and Linda S. Dix (eds.), National Research Council, *Recruitment, Retention, and Utilization of Federal Scientists and Engineers* (Washington, DC: National Academy Press, 1990).

[71] Jonathan R. Cole and Stephen Cole, "The Ortega Hypothesis," *Science*, vol. 178, Oct. 27, 1972, pp. 368-372. Also see Sharon Levin and Paula E. Stephan, "Research Productivity Over the Life Cycle: Evidence for Academic Scientists," *American Economic Review*, vol. 81, March 1991, pp. 114-132.

[72] See Gene Bylinsky, "America's Hot Young Scientists," *Fortune*, vol. 122, No. 9, Oct. 8, 1990, pp. 56-69. Also see David Pendlebury, "Science Leaders: Researchers to Watch in the Next Decade," *The Scientist*, vol. 4, May 28, 1990, pp. 18-19, 22-24; and A.L. Porter et al., "Citations and Scientific Progress: Comparing Bibliometric Measures With Scientist Judgments," *Scientometrics*, vol. 13, 1988, pp. 103-124.

[73] Harvey Brooks, "The Future Growth of Academic Research: Criteria and Needs," *Science Policy and the University*, Harold Orlans (ed.) (Washington, DC: The Brookings Institution, 1968), pp. 75-76.

[74] Researchers form informal networks according to their specialization in addition to the formal organizations in which they work. It is not known how changes in funding patterns affect informal as opposed to formal communication. See Leah A. Lievrouw, "Four Research Programs in Scientific Communication," *Knowledge in Society*, vol. 1, summer 1988, pp. 6-22.

A further aspect of concentration of funding, and one of mounting concern to universities and agencies alike, is the degree to which the Federal Government could promote participation in science by disadvantaged groups and by regions of the Nation that have not traditionally received large amounts of Federal research funds. Disadvantaged groups and potential scientists and engineers who are geographically dispersed in research are considered by many to be untapped resources that could enhance U.S. research capacity. At present, set-aside programs help to accomplish these goals (see box 7-F). A more concerted and sustained effort by the Federal Government to increase participation is warranted in the coming decade.

A final question is this: should the Federal Government focus its educational support on graduate fellowships, traineeships, and research assistantships (regardless of the combination), or spend a larger proportion of funds on undergraduate education and earlier segments of the pipeline? If one believes the projections of future shortages in Ph.D.s for the 1990s, then the Federal Government could produce many more Ph.D.s for the short term to meet the need, and then reconsider the question. If there are concerns about these projections (as OTA has ascertained), then the Federal Government could take a long-term view and work to enhance the supply throughout the pipeline. This would particularly argue for a greater investment in undergraduate science and K-12 education. As labor economist Alan Fechter writes:

> The relevant policy issue should be whether the expected equilibration mechanisms triggered to correct . . . imbalances will be consistent with national needs and more global social objectives. . . . If not, then policymakers will need to consider other mechanisms that will equilibrate supply and demand with minimal unwanted side effects.[75]

A key concern for the future of the research work force is not only the size of the pipeline, but the *composition* of the students in it. What is the relative proportion, especially at the doctoral level, of U.S. citizens and foreign nationals? The evidence presented in this chapter on the chronic underrepresentation of women, minorities, and the disabled among science and engineering Ph.D.s suggests that financial support mechanisms have discouraged certain segments of the talent pool from pursuing graduate study. How can the Federal Government, through direct financial incentives and institutional programs that can modify student aspirations, reverse this trend? The answers have implications not only for the size of the work force, but also for the character of the scientific work that new participation automatically brings to the Nation's research enterprise.[76]

Photo credit: University of Washington

A student in the Early Entrance Program at the University of Washington performs a physics experiment. Science education from K-12 through undergraduate levels is vital for preparing the science and engineering research work force.

Conclusions

The U.S. system of doctoral production has consistently displayed its excellence over the past 40 years. The number of doctoral scientists and engineers employed in the United States has grown by almost 50 percent since 1977. Nevertheless, several trends in the production of new Ph.D.s are of concern. Many also question whether shortages in the future U.S. scientific and engineering work force, and particularly its research component, are inevitable.

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[75] Fechter, op. cit., footnote 26, p. 19. Also see Lisa Simon, "Despite Scientist Shortage, Future Ph.D.s Fear Joblessness," *The Scientist*, vol. 5, No. 1, Jan. 7, 1991, pp. 24, 32.

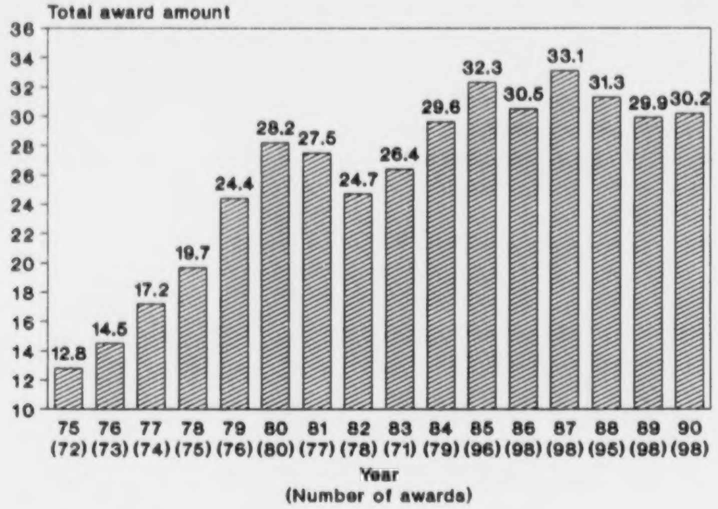
[76] For example, see Jerry Gaston, "The Benefits of Black Participation in Science," *Blacks, Science, and American Education*, Willie Pearson, Jr., and H. Kenneth Bechtel (eds.) (New Brunswick, NJ: Rutgers University Press, 1989), pp. 123-152.

Box 7-F—Minority Biomedical Research Support Program

As part of the National Institutes of Health's (NIH) effort to promote involvement of minority scientists in ongoing research, the Minority Biomedical Research Support (MBRS) Program awards grants to institutions with substantial minority enrollments. The purpose of the program is to support research by American Indian, Black, Hispanic, Native Alaskan, Asian, and Native Pacific Islander faculty and students in the biomedical sciences, and to strengthen the grantee institutions' biomedical research capabilities.[1]

Initiated in 1972, the MBRS Program was originally administered through the NIH Division of Research Resources, but in 1989 was moved to the National Institute of General Medical Sciences (NIGMS). Two- and four-year colleges, universities, and health professional schools with either 50 percent or more minority student enrollment or those with a demonstrated commitment to the assistance of minority students and faculty are eligible to apply for a project grant. The average annual grant is $350,000, the highest $1.5 million. MBRS Program grants may be used to support time for faculty members to engage in research; exploratory research and full-scale research activities through the purchase of equipment, supplies, and technical assistance; and undergraduate and graduate students working "hands on" in a faculty member's research. Figure 7F-1 shows the size and number of MBRS awards for the past 15 years.

Figure 7F-1—MBRS Awards and Funding: Fiscal Years 1975-90 (in millions of 1982 dollars)



NOTE: MBRS = Minority Biomedical Research Support.

SOURCE: National Institute of General Medical Sciences, unpublished data, August 1990.

Project review and management, including monitoring progress and negotiating budgets, are assumed by NIGMS. As a line item in the appropriation for NIGMS, the MBRS Program received over $28 million in fiscal year 1989. The program received an additional $11 million from other NIH components (which have contributed

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[1] What follows is based on National Institute of General Medical Sciences, "Minority Biomedical Research Support Program," administrative document, April 1990.

There are pitfalls in many of the methodologies employed in Ph.D. projections: their track record is troublesome. Most notably, OTA questions the ability of statistical analyses to predict future demand for Ph.D.s, especially when coupled with uncertainty about levels of Federal and industrial support for s/e research in the 1990s. Nevertheless, these trends should be monitored, and investments in the educational pipeline continued to ensure a robust supply of students. This is in the national interest, not just essential for science, engineering, and the research enterprise. For this reason alone, increasing the attention to teaching in research centers is warranted.

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for the past 13 years) to help support MBRS research projects of direct relevance to their own missions. Presently, 11 other NIH components and the Alcohol, Drug Abuse, and Mental Health Administration co-fund MBRS projects.

The MBRS Program has two funding mechanisms. The first, the traditional MBRS Program, provides support of up to $1.5 million per year for faculty members to carry out research projects. To be eligible, an institution must undertake at least 2 and no more than 25 research projects and must involve at least 2 faculty members having different research interests. A heavy emphasis is placed on involvement of undergraduate and graduate students in faculty research projects. The hope is that from this interactive relationship, a commitment to science will develop, and biomedical research will become an attractive career option for those students. While faculty members are expected to submit their work for publication in peer-reviewed scientific journals, the program also expects students to participate actively in the research, coauthor publications, attend scientific meetings, and give presentations.

The second component of the MBRS Program, the Program for Undergraduate Colleges and Two-Year Colleges, began in 1985 and supports enrichment activities, pilot research projects, and regular research projects. The maximum award under this program is $450,000 in direct costs over 3 years, plus indirect costs. A portion of these award monies must be applied toward "enrichment activities," such as workshops, attendance at scientific meetings, and summer research experiences in off-campus laboratories. In addition to the two primary award programs, the MBRS Program started supplemental funding for both instrumentation and animal resource improvement in 1983 and 1987, respectively.

Currently, institutions in 31 States are supported by the MBRS Program, with California and Puerto Rico having the most institutions participating in the program (nine and eight, respectively). Like many programs targeted to groups underparticipating in science, the MBRS Program represents a well-institutionalized model that could be generalized if funding permitted. As a recruitment and retention device, the program couples students to role models, previews science as a career, and builds institutional capability to compete for Federal funds and conduct collaborative, cutting-edge research. A significant number of awards are concentrated in southern States with large minority populations, such as Alabama, Georgia, and Tennessee. Thus, the MBRS Program, in conjunction with the other NIH efforts, is intended to produce a larger minority presence in the research work force.

While OTA has presented data on human resources in research, more detailed data could be collected. For instance, it is at best possible only to estimate, with presently available data, the size of the *research* work force. Based on the NSF estimates cited above, the U.S. s/e work force of academic Ph.D.s totals 340,000; those reporting research as a primary or secondary work activity total 155,000. So less than one-half (about 45 percent) of those in the academic sector are engaged at all in research, but this represents an unknown fraction of the total research work force. The proportions federally funded and the number of scientists and engineers leaving research careers are also unknown. Even less information exists on the evolution of research groups (and its effect on graduate training). Much anecdotal evidence and some personnel expenditure data from NIH and NSF indicate that research groups are becoming larger on average, yet the size of the distribution and its rate of growth are unknown. (The next chapter reviews the state of data on the research system, and presents suggestions for enhanced data collection in the Federal agencies and elsewhere.)

Based on the trends reviewed here, OTA finds that there is no current crisis in the Nation's ability to do scientific research. The Federal Government may wish to do nothing now to intervene in the Ph.D. production system and let market forces operate unencumbered. Federal funding will continue to serve the goal of excellence in research. If funding growth slows, however, the related goals of education and human resources risk becoming second-order priorities. All markets would be fortified by enhancing the education pipeline, especially at the undergraduate level, to ensure that future shortages can be met.

However, the composition of students in the pipeline—by gender, race/ethnicity, and nationality—is of greater concern. The scientific community could benefit from the diversity of research interests and approaches that new entrants bring, especially those from groups who have historically not participated fully in it. The Federal Government may also wish to consider, through new legislation, more extensive and long-term support for the recruitment of potential scientists and engineers from groups disadvantaged within s/e, as noted above. A diver-

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sity of personnel and career paths will distinguish the research work force of the 1990s.

Policies could be devised that target incentives for s/e labor markets disaggregated by field and sector. Research in many fields is moving toward a more "industrial" model, with larger teams, specialized responsibilities, and the sharing of infrastructure. In response, the Federal Government has acknowledged changes in the (sometimes interdisciplinary) composition and more complex structure of research groups through centers and block-grant funding. Perhaps it should now provide the impetus for universities to examine and experiment with their policies concerning the opportunities and rewards for nonprincipal investigators, e.g., postdoctorates and nontenure track researchers.

All policy initiatives will need to consider impacts on undergraduate and graduate teaching, the stress on the current academic model of research and education, and new models that might lessen institutional strain. Reauthorization of the Higher Education Act of 1965 by the 102d Congress will provide an opportunity to encourage universities to increase the rewards for undergraduate teaching and enhance undergraduate and graduate experience in diverse career paths. If this chapter has demonstrated anything, it is that human resources are a main business of the Federal Government, and not a marginal concern in strengthening the Nation's scientific research capability.

CHAPTER 8

Data on the Federal Research System

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CHAPTER 8

Data on the Federal Research System

> *The measurement process is also inherently limited by the inevitable human selection of both the phenomena to be measured and the type of data considered relevant to the purpose of the measurement effort. . . . For measuring an area as little understood as the science and technology enterprise, multiple models are needed to insure that as wide a spectrum of phenomena as possible is included.*
>
> U.S. General Accounting Office[1]

Introduction

While this report has characterized the Federal research system as it enters the 1990s, its mandate was broader. OTA was asked what data and analytical tools would be useful in describing the research system. Preceding chapters have drawn on much data. However, there are many areas in which additional information would be welcome. Data, in short, are an *issue* in Federal research policy, especially their form, gaps, and uncertainties. For example, OTA has discussed:

- variable definitions of "scientists" and "engineers" that can result in radically different estimates of their numbers (chapter 1);
- problems with using different deflators to calculate constant dollar trends in research funding (chapter 2);
- potential comparisons between congressionally earmarked and peer-reviewed projects (chapter 3);
- lack of information on how agencies process research proposals prior to awards (chapter 4);
- problematic estimates of research expenditures in megaprojects (chapter 5);
- need for comparative cost-accountability data, by institution and source, on research expenditures (chapter 6); and
- lack of baseline information on the Nation's research work force, as opposed to all scientists and engineers (chapter 7).

Data collected on certain aspects of the Federal research system—sources and dollars spent for research, academic degrees awarded, facilities and instruments, and various outcome measures such as publications and citations—are extensive.

In other areas, however, data are scarce, for example, details on the *research* work force (as opposed to the total science and engineering work force), or what proportion of investigators—across fields and agencies—are supported by Federal funds. Also, compared to the National Science Foundation (NSF) and the National Institutes of Health (NIH), the other research agencies devote few resources to internal data collection. Consequently, most analysis and research decisionmaking must draw conclusions from the NSF and NIH data systems. Since these agencies represent only part of the spectrum of research supported by the Federal Government, these analyses may omit key results and trends at other agencies, or skew findings toward biomedicine or academic research.

Furthermore, it is not clear how available agency data are used to inform decisionmaking, as some challenge current policy assumptions and others are reported at inappropriate levels of aggregation. For example, while there is much attention paid to the rising cost of instrumentation and facilities, indirect and personnel costs are rising at faster rates and account for larger shares of Federal expenditures. In this case, the issue is not information, but what can be done with it by decisionmakers.[2]

In this chapter, OTA first summarizes the data that are currently available. Table 8-1 lists the new data that OTA gathered and examined for this report.

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[1] U.S. General Accounting Office, *Science Indicators: Improvements Needed in Design, Construction, and Interpretation*, PAD-79-35 (Washington, DC: 1979), pp. 5-6.

[2] A distinction is made throughout this chapter between "decisionmakers" and "policymakers." The former comprise a considerably larger population, especially within the Federal research agencies; the latter are found at the very top of those agencies, as well as in the Office of Management and Budget, the Office of Science and Technology Policy, and Congress. Data speak to research decisionmakers at all levels, some of whom are not responsible for policies.

Table 8-1—Summary of OTA Data Collection and Analysis on Federally Funded Research

Description	Methods of collection	Subject
Original data collection and analysis:		
Federal agency analysis[a]	Interviews, site visits, and document review	Priority setting and funding allocation
University case studies[b]	Interviews and site visits	Rising research costs and responsiveness to changing priorities
Bibliometrics[c]	Citation analyses	"Hot" fields, related fields, university comparisons, and other indicators
Analysis of SEI[d]	Interviews and document review	Evolution of SEI volumes, data presentation, and future analysis
Researchers' views[e]	Surveys	Sigma Xi members' perceptions of Federal research funding issues
Secondary data analysis:		
Research cost comparisons[f]	NSF, NIH, and other datasets	Rising costs of research
Country surveys[g]	Interviews and document review	Priority setting, funding allocation, and research evaluation in other countries
Congressional earmarking[h]	Budget analysis and document review	Budget information on congressional funding and definitions of "earmarks"
Rhetorical analyses[i]	Document review	Historical analysis of research decisionmaking by different branches of government and goals of different ideological groups
Research evaluation[j]	Interviews and document review	Post-1985 developments in research evaluation in the United States and abroad
Analysis of Science Policy Task Force hearings[k]	Document review	Analysis of House hearings on science policy, 1985-87

[a] See box 4-A, chapter 4.

[b] See box 6-B, chapter 6.

[c] Henry Small and David Pendlebury, "Federal Support of Leading Edge Research," OTA contractor report, February, 1989; and Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990. See appendix F for information about how to obtain the latter report and all other OTA contractor reports listed below.

[d] Susan Cozzens, "Science Indicators: Description or Prescription?" OTA contractor report, July 1990.

[e] John Sommer, "Researcher Perspectives on the Federal Research System," OTA contractor report, July 1990.

[f] Kathi Hanna, "Federal Funding of Basic Research," OTA contractor report, November, 1990; and Harvey Averch, "Analyzing the Costs of Federal Research," OTA contractor report, August 1990.

[g] Ron Johnston, "Project Selection Methods: International Comparisons," OTA contractor report, June 1990.

[h] James Savage, "Academic Earmarks and the Distribution of Federal Research Funds: A Policy Interpretation," OTA contractor report, July 1990.

[i] See Mark Pollock, "Basic Research Goals: Perceptions of Key Political Figures," OTA contractor report, June 1990; and David Birdsell and Herbert Simons, "Basic Research Goals: A Comparison of Political Ideologies," OTA contractor report, June 1990.

[j] Harvey Averch, "Policy Uses of 'Evaluation of Research' Literature," OTA contractor report, July 1990.

[k] Patrick Hamlett, "Task Force on Science Policy: A Window on the Federal Funding and Management of Research," OTA contractor report, October 1990.

KEY: SEI = *Science & Engineering Indicators*; NSF = National Science Foundation; NIH = National Institutes of Health.

SOURCE: Office of Technology Assessment, 1991.

Second, OTA suggests additional information that could be collected, concentrating in areas of policy relevance and on data that are amenable to manipulation in the aggregate by Congress and the executive branch (especially the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB)), and at less aggregated program and project levels within the research agencies. The emphasis is on the analysis and presentation of data for monitoring changes in the Federal research system. Finally, OTA considers the utility of data for decisionmaking, revisiting the problems of evaluating research projects (and updating conclusions of a previous OTA study).

Information is not cost-free. While it can illuminate the operation of the Federal research system, for all participants and at many levels, the purpose is not to generate needless paperwork and impose new reporting requirements on the agencies. What may be appropriate for decisionmakers, in fact, is less information, not more, along with better measures and methods of applying and coordinating it.

What Data Are Available on the Federal Research System?

Many organizations collect and analyze data on the research system. First and foremost, is NSF, with its numerous surveys, reports, and electronic data systems that are publicly available. Other sources include the other Federal research agencies; the National Research Council (NRC); the Congressional Research Service (CRS); professional societies, especially the American Association for the Advancement of Science (AAAS); and other public and special interest groups.[3]

Together these databases and analyses provide a wealth of information: time series on the funding of research and development (R&D); expenditures by R&D performer (e.g., universities and colleges, industry, Federal laboratories), by source of funds, and by type (basic, applied, development); numbers of students who enroll in and graduate with degrees in science and engineering (s/e); characteristics of precollege science and mathematics programs and students in the education pipeline; and size, sectors of employment, and activities of the s/e work force (especially Ph.D.s in academia). Detailed analyses of the Federal budget by research agency are available each year, and impacts on specific disciplines and industries can often be found.

NSF publishes many annual or biennial reports. These reports summarize budget data from the Federal agencies, academic R&D (which is covered extensively, as academia is NSF's primary client), research at the Federal laboratories, funding and performance of research by industry, academic equipment and instrumentation expenditures, international comparisons, geographic distributions of R&D funds, and other topics. NSF also publishes detailed information on students, degrees awarded, employment by sector, and the people who perform research. Finally, NSF issues many individual reports on specific topics either requested by Congress or of particular interest to the scientific community.

Photo credit: National Aeronautics and Space Administration

An astronaut spins liquid in zero gravity aboard the Space Shuttle Columbia to test the separation of bubbles from the liquid. Research can take place in many different settings.

Certainly the most visible compendium of data on the research system is the biennial report, *Science & Engineering Indicators* (SEI), issued since 1973 by the National Science Board (NSB), the governing body of NSF.[4] At 1976 hearings,[5] NSB chairman Norman Hackerman traced the origins of SEI to a congressional mandate to NSB for its annual report, which was to focus on ". . . the status and health of science and its various disciplines (including) an assessment of such matters as national scientific resources, . . . progress in selected areas of basic scientific research, and an indication of those aspects of such progress which might be applied to the needs of American society."[6] From the outset, then, the SEI project aspired to measure and evaluate the results of federally supported R&D.

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[3] For a summary of major databases on science and engineering (individuals and institutions), see National Research Council, *Engineering Personnel Data Needs for the 1990s* (Washington, DC: National Academy Press, 1988), app. A-2.

Table 8-2 lists eight broad categories of data that have appeared in SEI, including impacts and assessments, resources, scientific performance, economic performance, international contacts, cross-sectoral linkages, literacy, educational pipeline, and scientific work force. Table 8-3 shows the distribution of tables among data types in the nine SEI reports. Even this broad-brush picture reveals a highly dynamic volume. Over the years, 79 distinct subcategories of data have appeared, about one-half in the original 1972 volume and about one-half added later. The categories of international and cross-sectoral contact, literacy, and pipeline show steady patterns of expansion in types of data. Resources, impacts and assessments, and scientific performance indicators have been stable, with some new types added. The economic performance indicators show high turnover—many categories added and some dropped. Publication and citation measures are still the main forms of scientific performance data.[7]

SEI stands as the most comprehensive look at the research system that is currently available. Some find fault with the volume, however, because it is based on an input/output model of science (i.e., "people and money enter the system, research comes out"), which is thought to be simplistic, omitting quantitative (and qualitative) measures of the *process* of research.[8] Others criticize SEI for its concentration on academic or academically based research and lack of emphasis on the research-technology interface.[9]

Each year, CRS and AAAS publish perhaps the most comprehensive and widely read compilations of Federal R&D spending (the former focuses on appropriations, the latter on the proposed "R&D budget"). These documents help to interpret, by placing into an historical frame, the appropriations bills signed into law by the President. Various professional societies, e.g., the American Chemical Society, also compile surveys of R&D spending, salaries, and employment opportunities that are of particular interest to their constituencies. In addition, the American Council on Education, the Council of Graduate Schools, and the Association of American Universities publish annual and occasional reports that characterize trends in research university expenditures, administrator and faculty

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[4] The following discussion of *Science and Engineering Indicators* (SEI) is based on Susan E. Cozzens, "Science Indicators: Description or Prescription?" OTA contractor report, July 1990. Available through the National Technical Information Service, see app. F. Note that SEI was named *Science Indicators* until 1987. *Science & Engineering Indicators* builds on data collected, published, and issued in many other reports by the Science Resources Studies Division of the National Science Foundation.

[5] The timing of these hearings was important in the development of the Indicators series. The 1972 volume had been assembled in the course of a few months by one staff person working with an enthusiastic and energetic Board committee. After a stormy and uncertain process of approval both within the Science Board itself (who could not agree on how the numbers should be interpreted) and at the Office of Management and Budget and the White House (who thought it presented administration policy in too unfavorable a light), the volume appeared amidst considerable fanfare in the science and general press (as reported by Robert Brainard, the National Science Foundation staff member who prepared the first report). See U.S. Congress, House Committee on Science and Technology, Subcommittee on Domestic and International Scientific Planning and Analysis, *Measuring and Evaluating Results of Federally Supported Research and Development: Science Output Indicators—Part I. Special Oversight Hearings*, 94th Cong., May 19 and 26, 1976 (Washington, DC: U.S. Government Printing Office, 1976).

[6] Ibid., p. 7.

[7] The bibliometric database has added more to the categories of international and cross-sectoral contacts than it has to measures of scientific performance.

[8] For other volumes that address these issues, see National Academy of Sciences, *The Quality of Research in Science: Methods for Postperformance Evaluation in the National Science Foundation* (Washington, DC: National Academy Press, 1982); Y. Elkana et al., *Toward a Metric of Science* (New York, NY: Wiley, 1977); and H. Zuckerman and R.B. Miller (eds.), "Science Indicators: Implications for Research and Policy," *Scientometrics*, vol. 2, October 1989, special issue, pp. 327-448.

[9] Cozzens, op. cit., footnote 4. Because *Science and Engineering Indicators* (SEI) should reflect analytical advances in characterizing science and technology, provision could be made for the support of relevant research communities outside of the National Science Foundation (NSF). According to NSF's Carlos Kruytbosch (personal communication, December 1990), at the very least ". . . biennial post-publication workshops to evaluate the SEI report are workable and could be productive."

Table 8-2—Categories of Data in *Science & Engineering Indicators*

International contacts	Cross-national citations and coauthorships, publishing in foreign journals, participation in international scientific congresses, employment plans of foreign students, U.S. students and academics going abroad.
Cross-sectoral linkages	Citations from patents to the scientific literature, cross-sectoral coauthorship, cross-sectoral citation, mobility between sectors, university patenting.
Economic performance	• Patents, trade and trade balances, productivity measures, global investments, innovation indicators, high-technology business sector, venture capital.
Impacts and assessments	Public views on allocation of resources for science, judgments of benefit and harm from science and technology, prestige of scientists, expectations of scientific advances and problems caused by science, differences between the attentive and general public.
Literacy	Enrollments in science and mathematics, course content and testing requirements, achievement and test scores, teacher characteristics and activities, public understanding of scientific concepts, public use of technologies, student attitudes toward science and technology.
Pipeline	College and graduate school enrollments in science, engineering, and mathematics; degrees; test scores and other quality measures; preferences and plans of high school and college students; sources of student support.
Resources	Expenditures and obligations, special research resources, instrumentation and facilities.
Scientific performance	Publication and citation counts, Nobel Prizes.
Work force	The science and engineering work force: comparative measures, demographic characteristics, career variables, sources of support, technicians, stock and flow analysis.

SOURCE: Susan Cozzens, "Science Indicators: Description or Prescription?" OTA contractor report, July 1990.

issues, and Federal support for education and research.[10]

Recently, the Government-University-Industry Research Roundtable of the National Academy of Sciences, with data compiled by NSF's Policy Research and Analysis Division, provided much useful analysis on the state of academic R&D and changes since the early 1960s.[11] In addition, NRC periodically publishes reports on sectors of the research system and on the availability of data to characterize the system.[12] These publications provide a basis for understanding the Federal research system. But even with each of these organizations devoting significant resources to the collection of information, better data are needed to guide possible improvements of the system.[13]

What Data Are Needed?

Recognizing that data collection is often very difficult, and certainly time consuming, OTA concentrated on notable gaps in the empirical baseline. One overarching problem is that comparable data

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[10] A monthly compendium that announces and annotates new reports containing data and analysis on trends in science and engineering is *Manpower Comments*, published by the Commission on Professionals in Science and Technology, a participating organization of the American Association for the Advancement of Science.

[11] Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington, DC: National Academy Press, October 1989).

[12] For example, see National Research Council, *Surveying the Nation's Scientists and Engineers: A Data System for the 1990s* (Washington, DC: National Academy Press, 1990). Under multiagency support, the National Research Council collects, analyzes, and disseminates information on Ph.D. recipients. For a statement of its cross-cutting role, see National Academy of Sciences, *The National Research Council: A Unique Institution* (Washington, DC: National Academy Press, 1990).

[13] These efforts must also be seen in the context of the massive Federal data system. The components most relevant to research are the data series compiled and reported by the Census Bureau, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and the National Center for Education Statistics. The point is illustrated by calls for ways to measure how many people who aspire to attend college actually enroll. In the words of one sociologist: "We care to know on a month-to-month basis what the unemployment rate is. I think we ought to care to know on at least a year-to-year basis what the rate of access to higher education is." Quoted in Thomas J. DeLoughry, "U.S. Asked to Set Student-Aid Goals for Poor and Minority Students," *The Chronicle of Higher Education*, vol. 37, No. 20, Jan. 30, 1991, p. A20.

Table 8-3—Trends in Distribution of Data Among Categories in *Science & Engineering Indicators*: 1972-88

Number of tables

	1972	1974	1976	1978	1980	1982	1984	1986	1988	Total
Resources	38	63	57	58	41	52	49	47	60	465
Work force	18	37	35	35	54	37	29	38	30	313
Economic performance	9	31	47	22	40	37	20	35	45	286
Impacts and assessments	21	14	21	0	39	35	19	29	18	196
Pipeline	23	13	9	3	1	14	22	29	26	140
Literacy	1	0	0	0	1	4	14	46	54	120
Scientific performance	2	10	11	10	11	15	7	4	7	77
International contacts	0	2	8	10	11	11	11	9	8	70
Cross-sectoral contacts	0	3	0	3	8	7	6	12	7	46
Nonindicators	0	0	0	0	1	1	1	0	3	6
Total	112	173	188	141	207	213	178	249	258	1719

Percent of total

	1972	1974	1976	1978	1980	1982	1984	1986	1988	Total
Resources	34	36	30	41	20	24	28	19	23	27
Work force	16	21	19	25	26	17	16	15	12	18
Economic performance	8	18	25	16	19	17	11	14	17	17
Impacts and assessments	19	8	11	0	19	16	11	12	7	11
Pipeline	21	8	5	2	0	7	12	12	10	8
Literacy	1	0	0	0	0	2	8	18	21	7
Scientific performance	2	6	6	7	5	7	4	2	3	4
International contacts	0	1	4	7	5	5	6	4	3	4
Cross-sectoral contacts	0	2	0	2	4	3	3	5	3	3
Nonindicators	0	0	0	0	0	0	1	0	1	0
Total	100	100	100	100	100	100	100	100	100	100

NOTE: Each table, text, or appendix is counted once.

SOURCE: Susan Cozzens, "Science Indicators: Description or Prescription?" OTA contractor report, July 1990.

associated with the research operations of *all* the Federal agencies are lacking. NSF and NIH conscientiously log data on what proportion of proposals submitted to them are awarded funding, the number of researchers they support, expenditures by categories of project budgets (e.g., indirect costs and personnel), and other dimensions related to management of their research programs. However, other agencies collect only R&D budgetary information, primarily in response to OMB requests and NSF surveys of research conduct. Much more data could be collected on research funding and performance in these agencies. In particular, further information could be collected on proposal submissions as well as awards, research expenditures by line items of the budget (requested and expended), and the size and distribution of the research work force that is supported. Comparable data from the agencies are important for decisions that span agencies or broad segments of the scientific community. With the data that are currently available, Congress and other Federal policymakers risk overgeneralizing from what is known about research performance that is supported by NSF or NIH.

Some advocate that NSF should be the sole agency to centralize and standardize the analysis, especially since NSF has the mandate to collect R&D funding data from the other research agencies.[14] However, OTA found that the research agencies are sufficiently diverse in their organization and funding structures to create difficulties for any outside agency to translate data in comparable ways.[15] For example, breakdowns of R&D into basic research, applied research, and development are very difficult to measure and often judgments are made after-the-fact. NSF fields a survey to all Federal R&D agencies asking for detailed estimates of spending in various categories. Because of problems with applying definitions and with converting agency accounting of research dollars into the separate categories, however, many of the agencies claim that it is impossible to provide accurate answers to the NSF survey.

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[14] See Commission on Professionals in Science and Technology, *Measuring National Needs for Scientists to the Year 2000*, report of a workshop, Nov. 30-Dec. 1, 1988 (Washington, DC: July 1989).

[15] Although problems may exist with definitions, compliance by the reporting organizations with whatever definitions are used is also an issue. The advantage of an interagency mechanism, such as the Office of Science and Technology Policy's Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) committees, is its place in the Federal hierarchy: the agencies are likely to be responsive to requests for "crosscutting" information where budgets are at stake. The FCCSET Committee on Physical, Mathematical, and Engineering Sciences, for example, currently has a "structure of science" activity that includes the solicitation of data from the research agencies similar to those sought in this OTA study.

In 1989, NSF continued its effort to develop a better taxonomy of the research it funds.[16] "Fundamental," "directed," and "development" seemed to be the preferred categories, though some programs found it difficult to translate currently supported projects into these three categories. Unfortunately, any taxonomy would suffer from arbitrary divisions of research topics among categories. Also, "basic" and "applied," or similar definitions, are rarely used by managers to allocate monies; rather these distinctions are most important to the researchers who perform the research, since basic research is synonymous with enhanced investigator discretion over research directions, while applied research is often associated with the attainment of specific objectives.[17] Consequently, basic and applied divisions are less important for decisions that concern specific programmatic goals; however, they are quite important to decisions about the science base supported by the Federal Government.

Enhanced data collection at each agency would help NSF fulfill its data mandate, and advance development of comprehensive research strategies, especially programs that span agencies.[18] Other data that could be very useful fall into four categories: 1) research monies—how they are allocated and spent; 2) personnel—characteristics of the research work force; 3) the research process—how researchers spend their time and their needs (e.g., equipment and communication) for the conduct of research; and 4) outcomes—the results of research.

Research Monies

While the data collected on research sponsored by the Federal Government are abundant, information on research expenditures is not. In particular, direct and indirect costs in all sectors of the research system supported by the Federal Government could be monitored.[19] NSF and NIH have collected longitudinal data on research expenditures in individual investigator grants, but complementary data are needed on expenditures in Federal and industrial laboratories, research supported by other agencies, and on other types of research groups and cooperative ventures such as centers and university-industry collaborations. These data would help to monitor fluctuations in research expenditures. At present, predictions of future spending merely extrapolate from the gross totals disaggregated by sector, while individual components of the budgets may be increasing or decreasing relative to overall trends. These data would be especially helpful for revising estimates of start-up and operating costs in science megaprojects.

Another measure that would refine the knowledge of research expenditures would be breakdowns by field. (This is available for some academic research disciplines and Federally Funded Research and Development Centers only.) Many claims are made about the cost requirements of specific fields. For instance, research in some physics specialties is inherently more expensive than in others, because of the equipment required by research groups. At present, there are no means to evaluate these claims.[20] Yet for decisions that must balance the present and future needs of different sectors of the research system, such cost estimates and the trends associated with them could be very important.

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[16] NSF Task Force on Research and Development Taxonomy, "Final Report," unpublished document, 1989. For an earlier effort, see National Science Foundation, *Categories of Scientific Research* (Washington, DC: 1979).

[17] See Harvey Averch, "The Political Economy of R&D Taxonomies," *Research Policy*, forthcoming 1991; and Richard R. Ries and Henry Hertzfeld, "Taxonomy of Research: Test of Proposed Definitions on the NSF Budget," unpublished document, n.d.

[18] For example, the National Institutes of Health sets aside 1 percent of its research budget for research evaluation and internal analysis of the investigators and programs it supports. The Department of Energy, the National Aeronautics and Space Administration, the Office of Naval Research, and the National Science Foundation have all conducted ad hoc inhouse evaluations of the research they support and the efficiency of the operations needed to select and manage various research portfolios (see below). For an example of agency-based research evaluation data that could be assembled in an ongoing way, see Daryl E. Chubin, "Designing Research Program Evaluations: A Science Studies Approach," *Science and Public Policy*, vol. 14, No. 2, April 1987, pp. 82-90.

[19] This monitoring is not the same as the auditing of cost data by category of expenditure, as mandated by Office of Management and Budget Circular A-21 and as conducted by the Department of Defense and the Department of Health and Human Services contract audit agencies. That is done for accountability purposes. Congress seeks better information on how investigators and their teams actually spend money in the course of executing federally funded research projects, which requires some demystification of university accounting schemes. For examples of studies of data audit methodologies, see the new quarterly journal, *Accountability in Research: Policies and Quality Assurance*, edited at the University of Maryland School of Medicine.

Finally, data on how Federal agencies allocate monies within project budgets could be compiled. Agencies have much experience in negotiating budgets. Data would illuminate how judgments are made about specific categories of expenditure, e.g., in reducing "inflated" budget requests of investigators, imposing an artificial ceiling on equipment purchases, or adjusting allocations through NIH's practice of "downward negotiation." Since personnel costs have grown quickly compared with other research expenditures, financial analyses would be greatly enhanced by better personnel data.

Personnel

One of the most fundamental pieces of information on the research system is the size of the *research* work force, both in absolute numbers and as a fraction of all U.S. employed scientists and engineers. These numbers depend on how "researcher" is defined.[21] While estimates exist of the rise in Ph.D. personnel employed in research universities, very little detailed data exist for industry or other sectors of the research system. Estimates of the *positions* held by Ph.D. personnel in academia are inadequate. Distinguishing nonfaculty research associates from postdoctoral fellows and full-time equivalent faculty is analytically important—and a nightmare to sort and track over time. Accurate estimates of the changing size of the research work force and how many are federally funded—and are seeking such support—would aid in measuring current and unfunded academic research capacity. In addition, accurate estimates of the numbers of researchers exiting the system would help to gauge the attractiveness of specific fields, as well as the category "science and engineering" relative to other occupations.[22]

Another trend that has been noted in this report, mostly with anecdotal evidence and inferences from analyses of expenditures, is the increasing size of research groups, both within the university structure and through Federal support of centers. This trend has policy implications for the cost of research, its interdisciplinary capabilities, and the changing demographics of the work force. It also reflects how researchers may spend their time. More data on "production units" in research and their dependence on Federal funding relative to other sources would augment enrollment, Ph.D. award, and work activity data. Changes in the structure of production units have also influenced the research process and the volume—and perhaps the character—of outcomes.[23]

Research Process

"How research is done" has evolved since the 1960s. In particular, the organization of research groups and the settings in which research is conducted have changed.[24] Data on the conduct of research would aid in understanding the opportunities and stresses on the Federal research system and in planning how the research system can adapt to changing conditions.

For instance, it is often claimed that researchers are spending much more time writing proposals, and that their research suffers as a consequence. No systematic data exist either to support or refute this claim. While it is in the interest of Federal sponsors for their grantees to spend as much time as possible in the conduct of research, investigators report that the increased competition for Federal funds compels

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[20] For a recent effort to look comprehensively at Federal support, by agency and over time, of one sector of one field, see American Chemical Society, Department of Government Relations and Science Policy, *Federal Funding of Academic Chemistry Research, FY 1980-FY 1988* (Washington, DC: November 1990).

[21] A "researcher" could be defined as anyone publishing a scientific paper (i.e., by authorship), possessing a Ph.D. (i.e., by credential), or working in a particular setting (i.e., by sector). Indeed, the problem of defining who is a "scientist" also applies here. See Derek de Solla Price, *Little Science, Big Science* (New York, NY: Columbia University Press, 1963). Also see National Research Council, op. cit., footnote 3.

[22] For a discussion of methodological pitfalls associated with assessing, for example, characteristics of the Federal work force, see U.S. General Accounting Office, *Federal Work Force: A Framework for Studying Its Quality Over Time*, GAO/PEMD-88-27 (Washington, DC: August 1988).

[23] The role of laboratory chief or team leader combines entrepreneurial and administrative/supervisory tasks. Both are essential to the funding and longevity of the productive research unit. On the emergence of the entrepreneurial role on campus, see Henry Etzkowitz, "Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science," *Minerva*, vol. 21, summer-autumn 1983, pp. 198-233.

[24] For a prophetic discussion, see B.C. Griffith and N.C. Mullins, "Coherent Social Groups in Scientific Change," *Science*, vol. 177, Sept. 15, 1972, pp. 959-964.

Photo credit: U.S. Department of Agriculture

Researcher picks blueberries—95 percent of the varieties of blueberries in production today were developed by Department of Agriculture scientists. Research is performed in many settings.

proposal writing.[25] However, one might expect that as the size of academic research groups grows, principal investigators will spend more time seeking money to sustain their larger research teams and programs.[26] This phenomenon is similar to strategies in a law or consulting practice, where the addition of less senior associates leverages the effort of the more senior employees to spend more time marketing and winning projects for the firm. In the academic research community, entrepreneurial pursuits are very different from research and teaching, and the additional burden can be a source of stress for senior researchers.[27]

Many also claim that increasing time commitments required by research pursuits hamper the ability of faculty to meet their teaching responsibilities. Data on how faculty apportion their time have been unreliable. Ironically, self-reports in compliance with Federal accountability requirements tend to distort estimates of time spent on various work activities.[28] Since the Federal Government invests in the academic research system to maintain a strong instructional as well as knowledge-producing capability, shifts in the activities of researchers is of central concern.

Data are needed on how apprentice, junior (e.g., postdoctorates), and senior researchers spend their time on research (collecting data and analysis), proposal writing, teaching (classroom and one-on-one), travel, presenting results to scientific colleagues, and other pursuits.[29] Differences between time commitments in Federal, industrial, and academic settings could also be judged.[30]

More generally, data could be collected on changing equipment needs. The average lifetime of a scientific instrument has shrunk during the 1980s from an average of 7 years to less than 5 years.[31] Additional data could address such questions as: how does the reliance on equipment vary across fields? What happens to obsolete equipment? As communications and other technologies progress and the scientific community comes more to rely on them, these questions will increasingly impact Federal funding.

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[25] For example, see *Science: The End of the Frontier?* a report from Leon M. Lederman, President-Elect to the Board of Directors of the American Association for the Advancement of Science (Washington, DC: American Association for the Advancement of Science, January 1991).

[26] See D.E. Chubin and T. Connolly, "Research Trails and Science Policies: Local and Extra-Local Negotiations of Scientific Work," *Scientific Establishments and Hierarchies*, Sociology of the Sciences, Yearbook vol. 6, N. Elias (ed.) (Dordrecht, Holland: D. Reidel, 1982), pp. 293-311.

[27] For evidence on entrepreneurial behavior, see Karen Seashore Louis et al., "Entrepreneurs in Academe: An Exploration of Behaviors Among Life Scientists," *Administrative Science Quarterly*, vol. 34, 1989, pp. 110-131.

[28] See Donald Kennedy, "Government Policies and the Costs of Doing Research," *Science*, vol. 227, Feb. 1, 1985, pp. 480-484.

[29] For example, data could illuminate changing patterns of communication among scientific colleagues. With new communications technologies, such as electronic mail systems and computer networks, scientists have the ability to exchange data and ideas much more often. Is science becoming more collaborative (or competitive) due to these innovations? Do most scientists have access to these technologies? Are some at a disadvantage without them?

[30] Some clues derive from in situ laboratory studies of scientists, for example, Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Beverly Hills, CA: Sage, 1979); and Bruno Latour, *Science in Action: How To Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press, 1987).

[31] See National Science Foundation, *Academic Research Equipment in Select Science/Engineering Fields: 1982-83 to 1985-86*, SRS 88-D1 (Washington, DC: June 1988). As the National Science Foundation's Leonard Lederman (personal communication, December 1990) points out, there is no information of average "equipment use rate," or what proportion of available time an instrument is in use.

A final area of "process" on which data would be instructive are the standards for achieving various positions in the scientific community. Many claim that graduate students must publish more papers to be offered first jobs after receipt of the doctorate or completion of a postdoctoral fellowship. What are the average age, experience postcollege (in years), and publication records of new hires at research universities, and industrial and Federal laboratories? For other promotions? Such data would help the Federal Government to track the changing research labor market.[32]

Outcomes of Research

Because of the fundamental and elusive nature of research, measuring its outcomes—in knowledge and education—is very difficult.[33] The most elusive outcome is cultural enrichment—the discovery and growth of scientific knowledge. As OMB Director Richard Darman has said (speaking of the proposed Moon/Mars mission): "No one can put a price on uplifting the Nation." Research has resulted in many benefits to the Nation and is funded precisely because of those benefits. This kind of benefit is nearly impossible to measure. However, there are some proxies.

When looking at research as a contribution to education, numbers of degrees can be tallied and assertions about skills added to the Nation's work force can be made. When looking at research as creating new knowledge, one tangible "output" is papers published by scientific investigators to communicate new information to their scientific peers. Communicating the results of scientific research to colleagues through publication in the open literature is considered to be an important, if not essential, feature of good research practice.[34] Perhaps the best approach is to construct workable indicators and include a rigorous treatment of their uncertainties.

Bibliometrics

One tool that has been vigorously developed (especially in western Europe during the 1980s) for measuring the outcomes of research is bibliometrics, the statistical analysis of scientific publications and their attributes. Intrinsic to scientific publication is the referencing of earlier published work on which the current work is presumably based or has utilized in some way. References are a common feature of the scientific literature, and by counting how often publications are cited, bibliometrics can arrive at a weighted measure of publication output—not only whether publications have been produced, but also what impact those publications have had on the work of other scientists.[35]

OTA has explored several examples of new data sets that could be compiled using bibliometrics.[36] First, universities can be ranked according to an output or citation measure, the citation rates for papers authored by faculty and others associated with each institution. OTA drew on the large electronic database created and maintained by the Institute for Scientific Information (ISI).[37] Each institution in ISI's Science Indicators database, 1973 to 1988, was listed by its total number of cited

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[32] For other suggestions, see Commission on Professionals in Science and Technology, op. cit. footnote 14. The above (hypothetical) data also raise the question of research outcomes—those relating to individual performance and that of other production units in the Federal research system.

[33] For a comprehensive review (now a decade old) of attempts at such measurement, see National Academy of Sciences, op. cit., footnote 8, especially ch. 2.

[34] Robert K. Merton, "The Matthew Effect in Science, II: Cumulative Advantage and the Symbolism of Intellectual Property," *Isis*, vol. 79, No. 299, 1988, pp. 606-623.

[35] Interpreting citation patterns remains a subject of contention. For caveats, see D.O. Edge, "Quantitative Measures of Communication in Science: A Critical Review," *History of Science*, vol. 17, 1979, pp. 102-134; and S.E. Cozzens, "Taking the Measure of Science: A Review of Citation Theories," *ISSK Newsletter*, No. 7, 1981, pp. 16-21. The definitive overview is contained in Eugene Garfield, *Citation Indexing: Its Theory and Application in Science, Technology and Humanities* (New York, NY: John Wiley & Sons, 1979). Also see Francis Narin, *Evaluative Bibliometrics: The Use of Citation Analysis in the Evaluation of Scientific Activity* (Cherry Hill, NJ: Computer Horizons, Inc., 1976).

[36] See Henry Small and David Pendlebury, "Federal Support of Leading Edge Research: Report on a Method for Identifying Innovative Areas of Scientific Research and Their Extent of Federal Support," OTA contractor report, February 1989; and Henry Small, "Bibliometrics of Basic Research," OTA contractor report, September 1990. For OTA contractor reports available through the National Technical Information Service, see app. F.

[37] The Institute for Scientific Information (ISI) database covers 7,500 journals published worldwide and indexes 800,000 new articles each year. The files derived from the ISI databases cover multiple disciplines and countries, and extend back to 1973. The analysis below is based on Small, op. cit., footnote 36. The Science Indicators File is a specially constructed multiyear file of publications from ISI's *Science Citation Index*, which contains a citation count time series for each paper in the file that has been cited one or more times for the years 1973 through 1988 inclusive.

Table 8-4—Mismatches in Rank Between Federal Funding and Average Citations: 1988

Of the top 100 (107) federally funded universities, only 17 did not make the top 100 citation list. They are (with funding rank in parentheses):

- Texas A&M (22)
- University of Florida (45)
- Woods Hole Oceanographic Institute (52)
- New Mexico State University (61)
- Louisiana State University (72)
- Utah State University (74)
- North Carolina State at Raleigh (75)
- Virginia Polytechnic Institute and State University (76)
- University of Kentucky (82)
- University of Dayton (86)
- University of Nebraska at Lincoln (89)
- Wake Forest University (95)
- University of Medicine and Dentistry of New Jersey (99)
- Washington State University (100)
- University of Missouri, Columbia (101)
- Medical College of Wisconsin (104)
- Rensselaer Polytechnic Institute (107)

Of the top 100 cited schools, only 17 did not make the top 100 (107) most funded schools. They are (with citation rank in parentheses):

- University of California, Santa Cruz (14)
- University of Oregon (23)
- SUNY, Albany (43)
- Rice University (58)
- University of California, Riverside (59)
- St. Louis University (70)
- Creighton University (80)
- University of Notre Dame (81)
- University of Houston (82)
- University of New Hampshire (84)
- University of Alaska (89)
- University of South Alabama (90)
- College of William and Mary (93)
- Howard University (94)
- Brigham Young University (96)
- University of Delaware (97)
- University of Oklahoma (98)

NOTE: To compare the top 100 rankings, some institutions in the top 100 federally funded universities were disaggregated by campus of the State university system, e.g., the University of Texas, Austin. This added 7 entries to the top 100.

SOURCES: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fiscal Year 1988*, NSF 89-326 (Washington, DC: 1990), table B-37; and Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990.

papers, the total citations received by all papers associated with each institution, and the ratio of number of citations to the number of publications, namely, the *average citations per cited paper*. This is a more discerning measure than either publication or citation counts alone. A ranking of institutions by average citation rates can be used in conjunction with the list of top universities in Federal R&D funding received to link inputs with outputs. (Appendix E lists the top 100 academic institutions ranked by their average citation impact for the period 1981 to 1988.) Table 8-4 lists the institutions, in 1988, that were among either the top 100 academic institutions in average citations or the top 100 receiving Federal R&D funds (again, see appendix B), *but not both*. Together, these measures illuminate differences in rank. The overlap in institutions suggests that the funding decisions by the Federal Government for the most part are leading to productive research. The mismatches may be indicative both of concentrated, rather than broad-based research productivity, and either some institutional "overachievement" or a substantial supplementation of Federal research support by State, corporate, and nonprofit sources.[38]

Trends in the average citation rate over time can also indicate how productive an institution has been in the published literature. The citation set can be analyzed by broad field or other variables to try to determine the cause of the changes (see box 8-A for profiles of four universities). Institutions can also be grouped to look at how, for example, "private institutions in the Southwest" or the national laboratories are performing as a category[39] (see figure 8-1). Many companies and other types of research organizations, despite proprietary inhibitions, also publish in the scientific literature and their work can be similarly aggregated and displayed[40] (see figure 8-2). In another example for future exploration, programs receiving primarily directed funds or block grants (e.g., in agriculture) could be compared with those that are investigator-initiated. This comparison would help to test the claim that targeted appropriations (e.g., earmarking) lead to the production of inferior research.

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[38] An institution that ranks high on funding and low on citation impact is not necessarily an underachiever. Some research is not readily published in the open literature, for proprietary or national security reasons.

[39] For example, the publication records and citation impact of National Aeronautics and Space Administration research centers, 1973 to 1988, are examined in "NASA's Citation Impact Dims in 1980s, But Voyager Missions and JPL Shine," *Science Watch*, vol. 1, No. 9, October 1990, pp. 1-2, 7-8.

[40] Biotechnology research is more often reported in the open literature than either research from electronics and computing firms or from Fortune 500 companies. Thus, the samples used in figure 8-2 may not represent the full range of research activity in these industries. Indeed, the most exciting results may be withheld from publication, but might be reflected in patents awarded later.

Box 8-A—Bibliometric Profiles of Four Research Institutions

OTA selected 19 institutions, based on historical patterns in their Federal funding profiles, to examine changes in research output and probe how they might be accounted for bibliometrically.[1] The institutions' publication and citation records were extracted to obtain a "citation impact" time series. This requires specifying four time points: a beginning and ending *cited* item period, and a beginning and ending *citing* item time period. This defines what items are eligible to receive citations and what journal publications are eligible to give them. OTA began with 1973, and defined the length of the period for analysis to be 8 years. This yields nine successive overlapping time windows that can be plotted as a time series or moving picture of the citation impact for each institution through 1988.

For example, counted in the first window were the number of cited papers published from 1973 through 1980 and the number of times those papers were cited by papers published in the same period. The ratio of these quantities is the mean citations per cited item for that time window. As a further normalization, each of the impacts is divided by the overall average for all U.S. papers for the specified time window, e.g., 1973 to 1980. The result is a measure of *relative impact*. Thus, a relative impact score of one signifies that the institution's average is identical to the average for all U.S. papers in the window. A score greater than one signifies an impact above the U.S. average, and a score below one an impact below the U.S. average.

The time series plots of relative impact for 4 of the 19 selected institutions are shown in figure 8A-1. To explain the trends observed in these graphs in terms of the fields of science involved, listings of the most cited papers were obtained for each institution, covering items cited 100 or more times, down to a maximum of 100 items.

1) *Massachusetts Institute of Technology* (MIT) has been consistently among the top 10 institutions for Federal R&D funds received. Like other top 10 institutions, which often produce relative impacts at the national average or above, MIT exhibits relative impacts in the 1.4 to 1.5 range. MIT also shows a modest gain in citation impact. Twenty-nine percent of its most cited papers are from the 1981 to 1988 period. Biomedicine has become stronger, while chemistry and geoscience have tapered off, and physics remained about the same.

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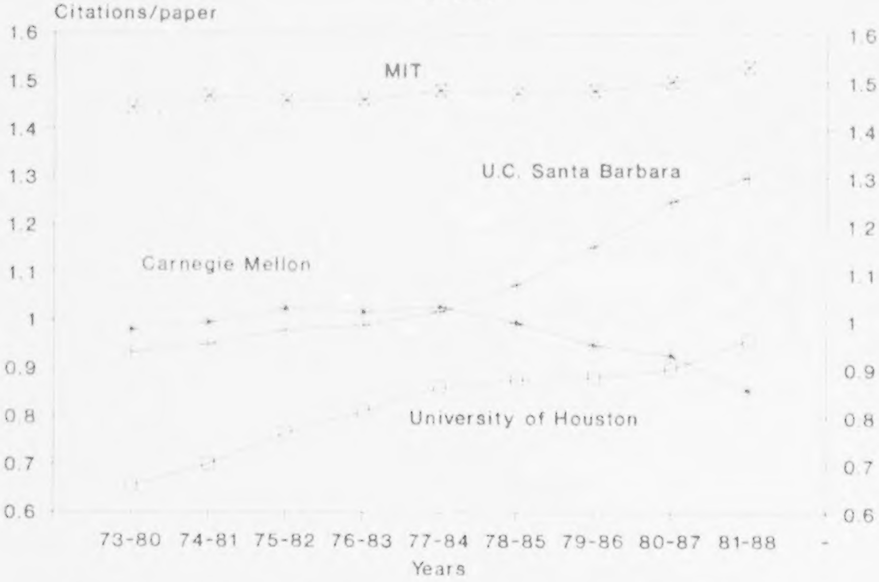
[1] The following is based on Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990. Available through the National Technical Information Service, see app. F.

Figure 8A-1—Average Relative Citation Impact for Four Research Institutions, 1973-88



SOURCE: Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990.

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2) *University of California-Santa Barbara* (UCSB) has improved its ranking among the top 100 recipients of Federal R&D dollars from 1967 to 1984. OTA calls such institutions "upwardly mobile." Their patterns of research output are even more diverse than their relative gains in funding. UCSB displays a very marked increase in citation impact. It also has a very large number of 1981 to 1988 papers in its highly cited set, 43 percent. Even more remarkable is the spread of these papers over various disciplines, with the emphasis on physics. Of the recent highly cited papers, 81 percent are in physics. Other areas represented include biomedicine, ecology, geoscience, and chemistry.
3) *Carnegie-Mellon University* (CMU) has been a top 20 recipient of Federal funds in engineering, and mathematics and computer science. However, it shows a decline in relative impact, beginning in the late 1970s. An analysis of the 78 papers cited 100 times or more shows that 15 percent of these papers are in the period 1981 to 1988. While 23 percent of the 1973 through 1980 papers were in the discipline of physics, only 8 percent are from physics in the later period. Chemistry, biomedicine, and computer science continue from earlier to later periods at comparable levels.
4) *University of Houston* (UofH) is a newcomer to the select group of top 100 recipients of Federal R&D funds. It displays one of the most marked increases in citation impact of the institutions examined, although it started at a very low level. Its number of papers cited over 100 times is also small at 28. Nevertheless, 39 percent of these are from the recent period. Whereas chemistry and biomedicine were dominant early, physics (and more specifically, high-temperature superconductivity) account for most of the new highly cited papers (though biomedicine is also represented). Possibly a shift toward strengthening physics contributed to the increase in impact for this institution.

In some of these cases, it may be possible to attribute changes in citation impact to a shift in the field orientation of an institution. Such shifts may be the result of deliberate organizational changes, or perhaps due to a resourceful faculty member who is able to move into new areas of research. One key to increasing impact is the ability to produce a continuing flow of innovative papers that influence researchers "at the front." This relates to the proportion of highly cited papers that are of recent origin. Reliance on aging "classics" will not ensure an upward trend in impact. Another factor is field balance: some institutions seem to have strength across a number of fields, while other institutions focus on one or two seemingly to the exclusion of others. It is clearly more difficult for an institution to maintain excellence across a wide range of fields—the traditional mark of a *research university*—than to specialize in one or two.[2]

One lesson from the institutional profiles is that maintaining a high citation impact over a generation is difficult at best. The citation trends for UCSB and UofH confirm their upward mobility in research output as well as in Federal funding, in contrast to the citation trends at other institutions.

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[2] Of the top 100 institutions in Federal R&D funding in 1988, only 39 had a relative impact score above the national average. Ibid.

Not only can publishing entities be analyzed, but fields of study as well. For instance, "hot fields," in which the rate of publication and citation increases quickly over a short period of time, can be identified. Research areas such as high-temperature superconductivity emerge after a major discovery. Through co-citation analysis, papers can be sorted into "clusters" of publications that cite each other. These research clusters can be grouped further and mapped within disciplines.[41] In addition, related areas that contribute to the work can be identified and linked across disciplinary boundaries. For example, high-temperature superconductivity research has been connected with work in ceramics, thin films, polymers, and other diverse areas.[42]

If the papers comprising a cluster cite their sources of funding, an estimate can be made of Federal support of the research represented by the clusters. To demonstrate this method, OTA requested that a small sample of papers published be searched for funding information in a cluster repre-

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[41] For elaborations of the algorithm and the interpretation of resulting co-citation maps, see Henry Small and B.C. Griffith, "The Structure of Scientific Literatures I: Identifying and Graphing Specialties," *Science Studies*, vol. 4, 1974, pp. 17-40; and Henry Small and Eugene Garfield, "The Geography of Science: Disciplinary and National Mappings," *Journal of Information Science*, vol. 11, December 1985, pp. 147-159.

[42] Small and Pendlebury, op. cit., footnote 36. These connections have been confirmed independently through analysis of other, nonbibliometric data. See John M. Rowell, "Superconductivity Research: A Different View," *Physics Today*, November 1988, pp. 38-46; and Dorothy Robyn et al., "Bringing Superconductivity to Market," *Issues in Science & Technology*, vol. 5, No. 2, winter 1988-89, pp. 38-45.

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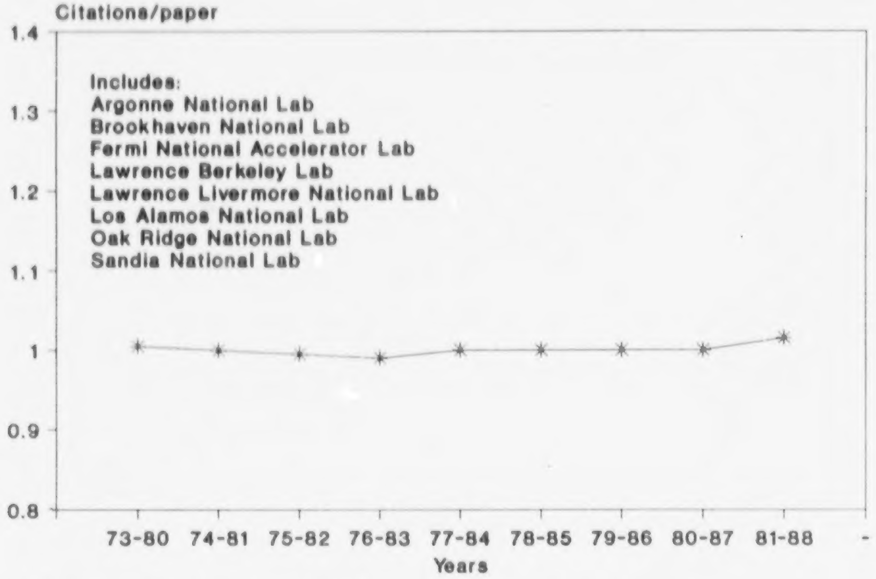
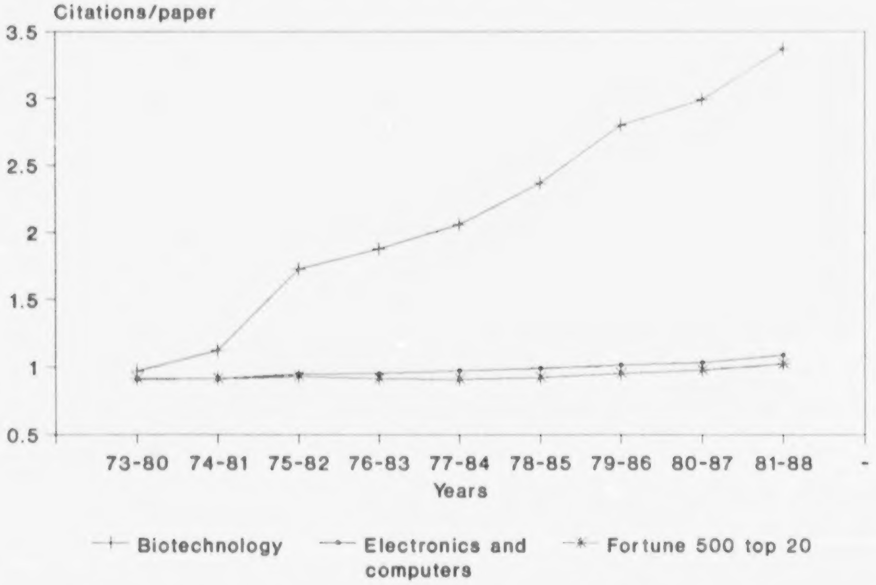
Figure 8-1—Relative Citation Impact for National Laboratories



SOURCE: Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990.

Figure 8-2—Relative Citation Impact for Three Industries



NOTE: *Biotechnology companies include:* Amgen, Biogen, Biotech Labs, California Biotech, Centocor, Cetus, Chiron, DNAX, Genentech, Genetics Institute, Immunex, and Molecular Genetics Inc. *Electronics and computer companies include:* IBM, Digital Equipment, General Electric, Westinghouse Electric, Eastman Kodak, and Xerox. *Fortune 500 Top 20 include:* General Motors, Ford Motor, Exxon, IBM, General Electric, Mobil, Philip Morris, Chrysler, DuPont de Nemours, Texaco, Chevron, Amoco, Shell Oil, Proctor & Gamble, Boeing, Occidental Petroleum, United Technologies, Eastman Kodak, USX, and Dow Chemical.

SOURCE: Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990.

Photo credit: U.S. Department of Energy

Researcher holds a piece of superconducting tape. Scientists must be able to make ceramic superconductors in a variety of forms to be useful—from thin films for electronics to casts for accelerator cavities. The development of ceramic superconductors has been an outcome of superconductivity research.

senting research directly related to high-temperature superconductivity. (Similar analyses were conducted in four other research areas.[43]) Roughly one-half of the most cited papers in 1985 to 1987 (77 of 139 papers) were coded for funding information and a random sample of the papers that cited them in 1989 were included (95 of 1561). More than one-half of the funding acknowledgments were to Federal funding agencies (with over one-half to NSF, slightly under one-third to the Department of Energy (DOE), and significant contributions from the Office of Naval Research and the National Aeronautics and Space Administration). Corporations, primarily IBM and AT&T, funded another one-third of the papers; Federal laboratories, private foundations, and foreign sources supplied the remaining funds. The Federal Government is a continuing catalyst of high-temperature superconductivity research.

The degree to which a field is international in effort can also be indicated through the nationality of authors. Again, for the high-temperature superconductivity cluster, the most cited papers in 1985 to 1987 were from the United States (64 percent), followed by France (8 percent), Japan (8 percent), Switzerland (4 percent), Canada (4 percent), and the United Kingdom (3 percent). The institutions in which these papers most often originated were AT&T (12 percent), IBM (12 percent), University of Houston (5 percent), University of Tokyo (4 percent), Bell Communications (4 percent), and the University of California-San Diego (3 percent). Countries citing the papers were more diverse, with the United States at 43 percent; Japan, France, and the Federal Republic of Germany at 5 to 6 percent each; the U.S.S.R. and India at near 5 percent; and the Peoples Republic of China at 4 percent. Similar diversity is seen in the institutions where these papers originated.

With these types of analyses, bibliometrics could perhaps be used to track the evolution of fields and subfields—by research topic and national or institutional authorship. However, there are significant disadvantages to bibliometrics, which also must be recognized.[44] In particular, citations are not made in a uniform way in the scientific community, and neither is allocation of authorship. Also, the same discovery may be cited in different ways in different publications. Consequently, only in the aggregate and when comparing similar fields with similar citation practices can judgments of hot fields, influential papers, and prolific authors be made with confidence.[45] The utility of bibliometrics should be seen as "value-added" to policy analysis, not as stand-alone information.

Other Measurement Techniques

Another genre of outcome measures focuses on the research-technology interface. There are many examples of data that could be collected to illuminate the relationship of research to other parts of the development cycle. Complicating features, however, include technological choice within private or public firms that develop technology, utilization of science and engineering talent, and the transfer of knowledge from research centers to other sectors of the economy.[46]

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[43] Small and Pendlebury, op. cit., footnote 36.

[44] As Eugene Garfield, founder of the Institute for Scientific Information (which pioneered citation databases and their analysis), warns: "You can misuse citation analysis easily—that's the story of my life." Quoted in Gina Kolata, "Who's No. 1 in Science? Footnotes Say U.S.," *The New York Times*, Feb. 12, 1991, pp. C1, C9.

[45] See Susan E. Cozzens, "Literature-Based Data in Research Evaluation: A Manager's Guide to Bibliometrics," final report to the National Science Foundation, Sept. 18, 1989.

Sponsors, at least for basic research, have little control over the execution of the projects they support. So lack of payoff may be unrelated to the intrinsic merits of project design and substance and have more to do with the differential competence and efficiency of performers. But no sponsor can ascertain the most competent, creative, and efficient of performers.[47]

In the case of public programs with firm measures of outcomes, negative evaluations suggest termination. But for programs whose output is information, the situation is highly problematic. Information volume and quality might be low, but this may be because the overall level of resources is too low. Or a program may have technical inefficiency due to poor management. Or the *lack* of results may itself have high scientific or technological value. Since research deposits knowledge into the scientific literature, it may take years to be applied to other problems. Some ideas are premature, and others remain invisible to specialists in fields different from the authors' own. Recognition of the utility of research—both intended and unintended—is often delayed.[48] This does not depreciate its value, but does impede its use.

Historically, science and technology are full of sudden reversals about the value of information produced by past research. Testing hundreds of compounds for superconductivity was, until recently, not considered high-grade science, but mundane science. And any evaluation of this work would have suggested that this kind of research was not worth much investment. Similarly, the funding of the early recombinant DNA projects was not done in the name of expected high payoffs. Certainly no one at the time imagined a biotechnology industry as the result. Thus, the ability of research evaluations to provide credible estimates of the incremental information gains from additional funding is weak. Federal agencies tend to use an insurance principle and spread resources widely to ensure that no reasonable bets are overlooked. (From one perspective, this is risk-averse; from another it is risk-taking, because ideas from out of the mainstream can be supported.)

Bibliometrics and production function data on the research-technology interface are examples of tools that could be used to evaluate outcomes. While not exhaustive, they illuminate different aspects of science as a process and the utility of research performance.[49] As with the examples discussed above, data collection can be improved when the user of the data and the purpose are targeted. The next section explores how data on the Federal research system is employed by policymakers and how new data could aid the transition from analysis to decisionmaking.

Utilizing Data

In a policy context, information must be presented to those who are in positions to effect change by allocating or redirecting resources.[50] In the diverse structure of the Federal research system, many actors play roles in research decisionmaking at many different levels. These actors require data reported in various forms and units to make decisions. For example, an agency program manager requires data specific to the purview of his or her programs, while OMB and OSTP must be aware of trends in science that span broad fields, institutions, and agencies, as well as those that apply only to specific fields, performers, and sponsors. Timely data are similarly important. For instance, world events can alter the perception and utility of even the best information and analysis (see box 8-B).

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[46] Given the large, but cheap increases in computing power, various models are commonly used by management analysts for deciding on ex ante investments, but these techniques remain very sensitive to subjective and highly uncertain estimates of technical and market success. One notable exception is Edwin Mansfield, ''The Social Rate of Return From Academic Research,'' *Research Policy*, forthcoming 1991.

[47] Recent advances in methods of measuring returns to basic research have centered on sophisticated econometric techniques for estimating *production functions* (e.g., measures of the economic impact of research). Since the marginal value of research is heavily dependent on downstream events, production functions could be embedded in fuller models of information flow and economic behavior. In addition, literally hundreds of *quantitative project selection* methods exist in industry for guiding investments. Methods include elaborate goal programming and analytical hierarchy models; the techniques are often known as return-on-investment, impact matrices, or checklists. See Harvey Averch, ''Policy Uses of 'Evaluation of Research' Literature,'' OTA contractor report, August 1990. Available through the National Technical Information Service, see app. F.

[48] See Gunther S. Stent, ''Prematurity and Uniqueness in Scientific Discovery,'' *Scientific American*, vol. 227, December 1972, pp. 84-93; and Julius H. Comroe, ''The Road From Research to New Diagnosis and Therapy,'' *Science*, vol. 200, May 26, 1978, pp. 931-937.

[49] The application of bibliometrics to patenting behavior, i.e., measuring the dependence of patents on the scientific literature, has pioneered new ways of thinking about the diffusion and application of research knowledge. See Francis Narin et al., ''Patents as Indicators of Corporate Technological Strength,'' *Research Policy*, vol. 16, 1987, pp. 143-155; and Zvi Griliches, ''Patent Statistics as Economic Indicators: A Survey,'' *Journal of Economic Literature*, vol. 28, No. 4, December 1990, pp. 1661-1707.

[50] For example, see Carol H. Weiss, ''Improving the Linkage Between Social Research and Public Policy,'' *Knowledge and Policy: The Uncertain Connection*, L.E. Lynn (ed.) (Washington, DC: National Academy of Sciences, 1978), pp. 23-81.

Providing data at each of these levels is a large task, but one that is essential. As seen with projected shortages of scientific and engineering personnel, trends are often specific to disciplines and to types of institutions, and decisions that take into account these differences would best address impending problems. Enhanced internal agency data collection would help to disaggregate and distinguish trends most relevant to the agency.

As well as targeting data collection to the needs of decisionmakers, the data above must address policy-relevant questions, i.e., be used evaluatively, as well as illuminate significant trends.[51] Thus, there has developed a distinction between standard data collection (i.e., tabulations on one variable, such as Ph.D.s awarded) and the development of *indicators*—data presented in such a way (e.g., comparisons between variables) as to suggest patterns not otherwise discernible. For instance, data on the rising cost of equipment in a specific field (or the rate of change in this cost) have little meaning unless compared with the cost (and percent change) of equipment in other fields. A measure of the *relative* cost of equipment in different fields would indicate the need to make special provisions for equipment in select fields. Similarly, data on the decline of baccalaureate degrees in a natural science field are more useful when they are compared to other broad fields, and judged in terms of absolute and relative declines and stability.

Indicators do not necessarily prescribe a course of action, but they warn of possibly significant trends. As part of the decision process, they offer ''usable knowledge.''[52] At present, indicators on the Federal research system are neither comprehensive nor objective-driven.[53] The focus of the *Science & Engineering Indicators* volumes has been less on indicators than on data. Indeed, SEI is a statistical reference book that collates available data on the research system. Additional efforts to produce indicators, especially on research performers, could greatly enhance utilization and action by decisionmakers.

New Indicators

NSF, specifically the Special Data Group attached to the Director's Office, has recently attempted to develop new indicators related to research participation at NSF during the 1980 to 1989 decade.[54] These indicators are defined and summarized in table 8-5. Though their meaning is not always straightforward,[55] these indicators represent a significant advance in reconstructing trends in NSF proposal and award activity.

The first indicator in table 8-5, the Proposal Success Rate, is driven by the change in the number of proposals submitted. At NSF, this number increased by 30 percent during the decade. Over 20 percent of those originally declined resubmit proposals to NSF (with an equal proportion submitting elsewhere). While the Proposal Success Rate declined from 38 percent in the beginning of the decade to 31 percent in 1989, PI (Principal Investigator) Success Rate from 1980-82 to 1987-89 remained above 40 percent. The PI Success Rate indicator allowed NSF to conclude that more PIs are being funded, but they facer stiffer competition to win awards. However, the relation between these two Success Rate indica-

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[51] The methodological pitfalls in applying data to evaluate national or institutional research performance are illustrated in John Irvine et al., ''Investing in the Future: How Much Governments Pay for Academic Research,'' *Physics Today*, September 1990, pp. 31-38; and Jeremy Cherfas, ''University Restructuring Based on False Premise?'' *Science*, vol. 247, Jan. 19, 1990, p. 278. For further discussion, see David C. Hoaglin et al., *Data for Decisions: Information Strategies for Policymakers* (Cambridge, MA: Abt Books, 1982).

[52] Charles E. Lindblom and David K. Cohen, *Usable Knowledge: Social Science and Social Problem Solving* (New Haven, CT: Yale University Press, 1979).

[53] Cozzens, op. cit., footnote 4, pp. 15-17.

[54] The Special Data Group is part of the Comptroller's Office at the National Science Foundation. It works independently of two other staffs in the Scientific, Technological, and International Affairs Directorate that also develop science indicators—the Science Resources Studies Division (home of the *Science & Engineering Indicators* volumes) and the Policy Research and Analysis Division (which in 1990 issued the data-laden, *The State of Academic Science and Engineering*).

[55] These are based on National Science Foundation, ''NSF Vital Signs: Trends in Research Support, Fiscal Years 1980-89,'' draft report, Nov. 13, 1990.

Box 8-B—War as a Wild Card: The Impact of the Persian Gulf Conflict on Science and Technology

After World War II came *Science—The Endless Frontier*.[1] A nation grateful for its success, and newly aware of its responsibilities in the world, decided that science was an important part of that world, and that science would benefit from government funding. Despite the negative impact of Hiroshima and Nagasaki, science came out of the war with a positive image, a great deal of momentum, and a strong basis for Federal support.

Vietnam, an unpopular war with unclear objectives, came with defoliation, napalm, Agent Orange, and accusations of environmental degradation. Science and technology, were cast in a negative light of the atomic bomb drops on Japan and tarred with the brush of destruction. Antiscience became part of the antiwar movement, and the remnants of this antiscience sentiment are still with us today.

The United States has just waged the most technological war the world has yet known.[2] For example, after years of controversy and failed test results, the Patriot missile served a cogent strategic and political purpose. Even with its outdated technology, the Patriot strengthened the claims of some that electronic warfare has come into its own. What such success may mean for the future image of science and technology is as yet unknown.

War is a wild card. Its effects on the populace at large (and on potential science and engineering students in particular) are difficult to predict. War is a reminder that events outside of science can reverberate in many ways—changing images and attitudes—for a long time to come. Analyses and reports on science and technology, such as this one, can only begin to measure, much less anticipate, these impacts.

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[1] **This box is based on a draft report by Alan McGowan, president, Scientists' Institute for Public Information, and a member of the Advisory Panel for this OTA report.**

[2] **See Sidney Perkowitz, "The War Science Waged," *The Washington Post*, Mar. 3, 1991, p. C2.**

tors and inferences about PI proposal-writing behavior is unclear for decisionmaking.[56]

The Continuity of Support indicator shows that nearly one in three of the PIs with NSF support in 1980 were still receiving support in 1989. The Flexibility of Support and Continuity of Support indicators together measure the balance between providing stable support to (established) investigators and retaining the ability to bring new investigators into the NSF funding system. Funding of new PIs fluctuated with the decline or growth in NSF obligations. Also, directorates with higher success rates (Geosciences, and Mathematics and Physical Sciences) ranked lower in Flexibility, because they are supporting a more established group of researchers.

The Award Size/Duration indicator reflects how NSF responded to increased demand for funding. Early in the decade, the number of awards was held constant but the award amounts were increased; later more proposals were funded and median award size did not grow. Throughout the decade, median annual award amount represented 80 to 85 percent of the *requested* amount.[57]

Indicators are best used to *monitor* trends, especially if they could be extended to other agencies as well.[58] This would help to complete the picture of PI proposal-writing strategy and the distribution of

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[56] Linda Parker, Comptroller's Office, National Science Foundation, personal communication, January 1991, suggests that more proposals are being submitted and the principal investigator population is increasing, but resubmissions (of previously declined proposals) account for only 20 percent of the growth. James McCullough, Comptroller's Office, National Science Foundation, personal communication, March 1991, reports that 30 percent of the proposals received by the National Science Foundation (NSF) in any year came from researchers who had not submitted in the previous 5 years (which NSF defines as "new investigators") and another 20 percent are received from researchers who submitted only one proposal. The supply of "new blood" and demand for funding seem hearty.

[57] Award amounts are negotiated. Principal investigators inflate their requests in the expectation that they will not receive "full" funding. If declined, their resubmissions tend to feature smaller budgets. In multiyear (e.g., 2 to 3 year) awards, which are now typical at the National Science Foundation, annual project budgets are fixed at the outset of the award, subject only to across-the-board cuts in succeeding years. (This contrasts with the National Institutes of Health's practice of annual downward negotiation in multiyear awards.) Robert P. Abel, Office of Budget and Control, National Science Foundation, personal communication, July 1990.

[58] The National Science Foundation cautions about the interpretation of indicator trends. Changes may be due to: a) an across-the-board budgetary upheaval, e.g., the Gramm-Rudman sequester of 1986, which reduces the capacity to fund; b) a targeted increase or decrease in appropriations to a directorate (or more generally, any agency line item); or c) agency reorganization or creation of programs that shifts proposals and awards in ways that affect disaggregated uses of an indicator.

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Table 8-5—New Indicators of Research Activity at NSF: Fiscal Years 1980-89

Indicator	Definition	Comment
Proposal Success Rate	Ratio of awards to total actions (new award and decline decisions) on competitive (peer- or merit-reviewed) proposals	Measures at an aggregate level proposal activity and awards that result in National Science Foundation (NSF) commitment of new funding. Interpretation of the indicator is not straightforward. Assumes estimates of growth in the research work force, rising costs of research, change in proposal review criteria, and a proliferation of special award categories (set-asides). The indicator does require knowledge of agency context.
PI Success Rate	Number of principal investigators (PIs) who are successful (within a 3-year period) in winning an award divided by total number of investigators submitting proposals (within the same 3 fiscal years)	Contrasts with Proposal Success Rate, which indicates NSF action generated by proposals submitted to it. Measures effort and success of the research population to gain NSF support, including changes in mean number of submissions needed to win one award.
Flexibility: New PI Funding	Percentage share of total award dollars going to PIs who have not had NSF support in the previous 5 years	Indicator is most revealing when compared to other indicators. Definition of "New PI" is only a proxy for "young investigators."
Continuity of Support	Percent of principal investigators receiving support at the start of a time period who are still receiving support at the end of the period	Indicator complements "Flexibility," which measures awards to investigators without prior awards. It can be indexed to any cohort of grantees and calculated for prior or succeeding years. Indicator identifies investigators with sustained support.
Award Size/ Duration	Total award dollars divided by total award years (duration)	Change from total dollars obligated in a particular fiscal year to amount of award over its lifetime provides a more accurate picture of support as experienced by the PI. Award size and duration affect the character and pace of research activity. Reduced award size may affect number of proposals written, while reduced duration may affect frequency of proposal writing. Both require investigator time for research. This indicator assumes no other, i.e., non-NSF, source of research support. It requires caution in making inferences about time spent in proposal writing.

SOURCE: Office of Technology Assessment, 1991, based on National Science Foundation, "NSF Vital Signs: Trends in Research Support, Fiscal Years 1980-89," draft report, Nov. 13, 1990.

research demand by field and agency. Thus, indicators could become an important part of the priority-setting process. Perhaps this argues for OSTP to coordinate across agencies the development and presentation of a prescribed set of indicators. Disaggregated to reflect disparate agency structures, such as directorates and divisions at NSF, such indicators could also help portray variations in fields and research communities. Sensitivity to such disaggregations may be most instructive for research funding policy. As an NSF task force recently put it:

> Part of the problem is a lack of understanding of the actual size of the research community and what fraction of a specific community should be funded. A clear, coherent picture of community size is essential. How many grants should be awarded and at what budgets? Should NSF fund all fields or make choices predicated on the investments of others? This "snapshot" of the community should be updated regularly in order to indicate achievement or changes that might be necessary to minimize confusion with respect to overall NSF policy issues.[59]

OTA concurs. Such baseline information should be routinely available to decisionmakers in the 1990s. Overall, *sets* of indicators that draw on these data are preferable to single measures. With this in mind, OTA (building on the new NSF indicators reviewed above) suggests the following four sets. They could be compiled and analyzed by all of the research agencies or by OSTP, which would complement existing indicators constructed and reported in

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[59] Some of the indicators presented above were indeed used for an inhouse evaluation of how to streamline the workload of the National Science Foundation's program staff and the external research community. Short-term recommendations focus on simplifying the proposal preparation and review process, including budgets; long-term recommendations include ways of balancing support modes and restructuring grant types (size and duration), especially cross-directorate programs. See National Science Foundation, *Report of the Merit Review Task Force*, NSF 90-113 (Washington, DC: Aug. 23, 1990).

SEI, to provide windows on various segments of the Federal research system:

- "Active research community" indicators, which would estimate the number of researchers actively engaged in federally funded research (e.g., PIs currently supported by one or more Federal grants plus those with a research proposal pending at a Federal agency, and proportion of research time that is federally funded).
- "Research expenditure" indicators to recalibrate Federal expenditures by line item of research budgets (e.g., salaries, equipment, and facilities) and by broad field.
- Federal "proposal pressure" indicators, e.g., proposals submitted to the Federal Government per investigator, ratio of Federal to (investigator's self-reported) non-Federal proposals and projects in force at the time of submission, and fraction of requested project budgets actually awarded by the funding agency.
- "Production unit" indicators, e.g., the size of the research team or other performing unit supported in part through Federal grants (disaggregated by subfield, institution type, and agency source).

The combination of such indicators would estimate more precisely the changing parameters of the Federal research system.[60] This information could be invaluable to policymakers concerned about the health of certain sectors of the system. To produce such information, as part of ongoing agency data collection and NSF responsibilities for collation and presentation, extra resources would be needed. They might come from streamlining current NSF data and analysis activities, such as a reduction in the number of nonmandated reports issued annually, or designating a special unit, much like the Science Indicators Unit, to expand its inhouse and extramural "research on research." If there is a premium on timely information for research decisionmaking, it must be declared (and funded as) a Federal priority.

The utility of data is judged by many participants in the system: the needs of Congress are usually agency- and budget-specific;[61] the agencies, in contrast, worry about the performance of various programs and their constituent research projects. Data converge in one other underutilized source of information—the evaluation of research projects and programs after they have (or have not) produced results.

Evaluation of Research

While data and indicators can provide valuable information on aggregate trends in the research system, it is much more difficult to evaluate specific research investments in agency programs or projects (apart from charges of fraud, incompetence, or other gross flaws, which are investigated as part of the congressional oversight function). The returns from the performance of research to society are quite diverse. They include economic, health, security, educational, and many other benefits. Because research is a public good, there is little incentive for private investment (in terms of social returns). In 1986, OTA looked at ways to measure the returns from public investments in research:

> In summary, OTA finds that . . . the factors that need to be taken into account in research planning, budgeting, resource allocation, and evaluation are too complex and subjective; the payoffs too diverse and incommensurable; and the institutional barriers too formidable to allow quantitative models to take the place of mature, informed judgment.[62]

Five years have passed since OTA announced this conclusion. However, demand for research evaluations has increased in all countries that make significant investments in research. The reasons for increased demand are the same: budgetary constraints, greater accountability to sponsors, and the

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[60] For example, what would be the indications that growth in research productivity is slowing or that the size of a research community is precariously large or small relative to the resources for supporting it? See Colleen Cordes, "Policy Experts Ask a Heretical Question: Has Academic Science Grown Too Big?" *The Chronicle of Higher Education*, vol. 37, No. 2, Nov. 21, 1990, pp. A1, A22.

[61] As several National Science Foundation staff have indicated to OTA project staff (personal communications, October-December 1990), the President's Science Advisor draws heavily on unpublished and newly published *Science & Engineering Indicators* (SEI) data in preparing and presenting the Administration's policy proposals at congressional "posture hearings" early in the annual authorization process. Indeed, the production cycle of SEI is geared to delivery of the volume as an input to this budget process.

[62] U.S. Congress, Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Returns?* OTA-TM-SET-36 (Washington, DC: U.S. Government Printing Office, April 1986), p. 9.

Photo credit: U. S. Department of Agriculture

Oversized thornless blackberries, tiny strawberry plants (in jars), and star-shaped slices of carambola (a tropical fruit now grown in Florida) are examples of outcomes of the Department of Agriculture's Agricultural Research Service programs.

desire for increased rationality in decisionmaking.[63] In response, many funding agencies—here and abroad—have formed evaluation units.[64] Research evaluators and designers of science indicators have carried out substantial work on measuring scientific and technological performance. There have been refinements in existing methods for evaluating research impacts ex post. Nevertheless, examination of the published and unpublished literature on research evaluation methods between 1985 and 1990 suggests that OTA's conclusion still stands: evaluation methods are not cited as guides to research decisionmaking by national governments.[65]

Since 1985, no methods have been invented that more definitively measure the scientific or social value of past research investments. By "definitively measure," OTA means that evaluation outcomes, whether positive or negative: 1) will be accepted without lengthy technical and political disputes among sponsors, clients, and constituents, and 2) will provide unambiguous direction in resource allocation or other kinds of decisions. While computer modeling permits greater use of ex ante (i.e., before the research project is attempted) project selection methods and ex post evaluation methods, the evidence is sparse that there is much short-term payoff to public or private sector research administrators from making greater use of them.[66]

The problem, however, may reside more with decisionmakers than the evaluation tools (and results) at their disposal. Research administrators have little incentive to use current evaluation technologies for making decisions about awards or level of project allocations. This lack of incentive persists because research evaluation ". . . occurs in a political context; is inevitably seen as *post hoc* justification for decisions (unrelated to the content of the evaluation); and should be anticipatory, designed to answer specific questions raised by superiors within the organization as well as critics from outside."[67]

Below, OTA first describes evaluation practices and processes around the world; then considers incremental improvements in research evaluation methods since 1985; and finally suggests that research evaluation faces certain inherent limits. These limits make it unlikely that however precise the measurement of average or incremental monetary or informational returns, they may not be embraced. Nevertheless, rather than a means of computing returns on past public investments or guiding prospective ones, research evaluation may help Federal funding agencies keep "on their toes," just as environmental impact statements impel agencies to assess the effects of their programs on the environment.[68]

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[63] Even countries that do not make significant research investments claim they evaluate. For example, Finland, Hungary, and Poland reported on their evaluation efforts in the "ECE Seminar on Evaluation in the Management of R and D, Apr. 3-7, 1989," unpublished proceedings.

[64] For discussions, see Ciba Foundation, *The Evaluation of Scientific Research* (New York, NY: John Wiley & Sons, 1989); and M. Gibbons and L. Georghiou, *Evaluation of Research: A Selection of Current Practices* (Paris, France: Organisation for Economic Cooperation and Development, 1987).

[65] An annotated bibliography on evaluation of research, 1985 to 1990, contains 147 works published in scientific journals and government documents. It is the basis for this section. See Averch, op. cit., footnote 47.

[66] K.M. Watts and J.C. Higgins, "The Use of Advanced Management Techniques in R&D," *Omega*, vol. 15, January 1987, pp. 21-29. This survey, consistent with past surveys, shows that R&D administrators prefer simple, transparent methods of project selection. Interestingly, OTA consistently finds in discussions with policymakers in the executive and legislative branches that the proposition "high yield from Federal investment in R&D" is taken as axiomatic. The issue is not *whether* to fund, but *what* and *how*.

[67] Chubin, op. cit., footnote 18, p. 84. Also see Harold Orlans, "Neutrality and Advocacy in Policy Research," *Policy Sciences*, vol. 6, 1975, pp. 107-119.

Evaluation in Other Countries

Table 8-6 summarizes the characteristics of the evaluation process among major scientific and technological powers.[69] Overall, in countries with parliamentary governments, national priority setting in research becomes a tool both of project selection and research evaluation.[70] The United Kingdom and France present contrasts in approaches to evaluation—the former contracting for outside analysis, the latter incorporating analysis of research outcomes into the government's apparatus and process for policymaking. Smaller countries, such as The Netherlands and Sweden, must be selective in the areas of research they target. If a "critical mass" of researchers is not available, collaboration in cooperative international projects becomes the only outlet for research participation.[71]

U.S. researchers have historically operated at the frontiers of knowledge, and other countries have adjusted their own research ventures as scientists in the United States and other scientifically advanced nations uncover promising areas. "Thus it is easier for countries *off* the frontier to identify what they want to pursue. Of course, the U.S. enterprise is so large that it uncovers more areas than smaller countries can afford. So they have a much more difficult choice than the United States in determining exactly what to pursue."[72] Now that the U.S. role as a research performer is changing in some areas so that U.S. scientists may not always be at the forefront,[73] the time may be ripe to review the place of research evaluations—especially relative to advances in other countries—in agency decisionmaking.

An Approach To Evaluating Basic Research Projects

Because of uncertainties attached to each and every research investment, procedures for their evaluation can be augmented by using ex post review by peer researchers and citation evidence jointly.[74] One approach would apply the following seven criteria weighted by the priority assigned to each:

1. value of the information produced: salience, relevance, importance—of both positive and negative results—to the field;
2. probability of use;
3. originality of results;
4. efficiency and cost;
5. impacts on education and human resources;
6. impacts on infrastructure and capability to carry out additional research in the future; and
7. overall scientific merit.

The overall ex post peer evaluation of particular projects can be compared with associated bibliometric information.[75] If this comparison indicates the same quality for a project, then the sponsor can have

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[68] See, for example, S. Taylor, *Making Bureaucracies Think: The Environmental Impact Strategy of Administrative Reform* (Stanford, CA: Stanford University Press, 1984); E.N. Goldenberg, "The Three Faces of Evaluation," *Journal of Policy Analysis and Management*, vol. 2, summer 1983, pp. 515-525; and R.V. Bartlett, *Policy Through Impact Assessment: Institutionalized Analysis as a Policy Strategy* (New York, NY: Greenwood Press, 1989). The idea is to induce decisionmakers to incorporate research evaluation information into their planning, not to impose the information under threat of punishment.

[69] The match between countries discussed in app. D of this report and those profiled in table 8-6 is not perfect. For recent comparative analyses among some of the countries considered here, see Department of Trade and Industry, *Evaluation of R&D—A Policymaker's Perspective* (London, England: Her Majesty's Stationery Office, 1988); L.L. Lederman et. al., "Research Policies and Strategies in Six Countries: A Comparative Analysis," *Science and Public Policy*, vol. 13, No. 2, April 1986, pp. 67-76; B.R. Martin and J. Irvine, *Research Foresight: Creating the Future* (London, England: Frances Pinter, 1989); and A.F.J. van Raan (ed.), *Handbook of Quantitative Studies of Science and Technology* (Amsterdam, The Netherlands: North-Holland, 1988).

[70] Averch writes: "Most European countries have ministries of science and technology that control the flow of resources for S&T. These ministries usually construct S&T plans correlated with economic plans. They are far more able to direct research programs at universities and industrial laboratories." See H.A. Averch, "New Foundations for Science and Technology Policy Analysis," paper presented at the Conference on The Mutual Relevance of Science Studies and Science Policy, Blacksburg, VA, May 12, 1989.

[71] See, for example, Jean-Francois Miguel, "Indicators to Measure Internationalization of Science," unpublished paper, 1989; and Francis Narin and Edith S. Whitlow, *Measurement of Scientific Cooperation and Coauthorship in CEC-Related Areas of Science*, vol. 1 (Luxembourg: Commission of the European Communities, May 1990).

[72] Averch, op. cit., footnote 70, p. 15.

[73] Some examples of hot fields dominated by non-U.S. researchers are presented in Small, op. cit., footnote 36.

[74] See, for example, R.N. Kostoff, "Evaluation of Proposed and Existing Accelerated Research Programs of the Office of Naval Research," *IEEE Transactions on Engineering Management*, vol. 35, November 1988, pp. 271-279.

[75] See John Irvine and Ben Martin, *Foresight in Science: Picking the Winners* (London, England: Frances Pinter, 1984).

Table 8-6—Characteristics of the Research Evaluation Process for Selected Countries

Government	Methods of evaluation	Types of research evaluated	Reported utility	Central evaluation units	Government standards	Reporting
United Kingdom . . .	Peer review citation; publication; rate-of-return; patents; checklists; market outcomes	Large projects; programs; universities; laboratories	Improve policy decisions	Assessment Office within Cabinet office; Department of Trade and Industry has central unit; some departments have Chief Scientists and Departmental Review Committees	Definitions of good practice	Some public
FRG	Economic and market indicators; ex post peer review for basic research projects; special committees; evaluations of disciplines; bibliometrics; patents; market outcomes	Large and small projects and programs	Improve policy decisions	Federal Ministry of Service and Technology (BMFT) has central unit	No	Some public
Japan	Consistency with plans developed by "foresight"; market tests for applied commercial projects	Projects; priority programs	Planning	New central science policy unit has some evaluation responsibilities	No	Some public
Netherlands	Peer review; publication-citation indicators for basic research; client satisfaction or utility for applied projects; profits earned from research contracts	Projects; basic research programs, universities,industrial research	Ensure consistency with plans; assist with allocation decisions	Yes in public agencies and universities	No	All public

SOURCE: Harvey Averch, "Policy Uses of 'Evaluation of Research' Literature," OTA contractor report, August 1990. Note that most of the literature on Japan discusses their R&D planning processes and the use of "foresight" methods. There is a less open literature on ex post evaluation.

greater confidence that the project is, in fact, of that quality. If the two measures are not congruent, then the project can be subjected to more intense analysis to explain the discrepancy.[76] In addition, an agency program can submit information on funded projects to experts working at the research frontiers to see whether its structure and content are judged as significant contributions to the field. This is expensive, but has been attempted, for example, for DOE's Basic Energy Sciences Program.[77] (For a summary, see table 8-7.)

Information is, of course, only one component of decisionmaking, and others may be of far more importance. Joint, cooperative evaluation of projects by researchers and decisionmakers—with participants inside and outside the research area being evaluated—could clarify agency portfolios and researcher needs.[78] Nevertheless, the impacts of some internal agency research may only become known years later.

Research evaluations can help raise difficult questions and uncertainties, but they cannot certify worth. There is simply no convincing way to judge the value of different kinds of research. However, until new techniques, which capture the research process as well as its products, are routinely used, research evaluations can best be employed to alert agencies to potential successes and problems, and to keep their programs vigilant in research decisionmaking (see table 8-8). Finally, these measurement techniques should be viewed only as one input to agency decisionmaking, because nothing can replace the experienced judgment of program managers and the scientific community to craft a successful research program.

Conclusions

There is a wealth of data on the Federal research system. However, data are most concentrated on Federal R&D funding in universities, degrees awarded in science, the science and engineering work force (especially the Ph.D. component), and some expenditure data by performers. Furthermore, the most detailed analyses are done almost exclusively at NSF and NIH, and not at the other major research agencies. The *highest priority* in data collection for research policymaking in the 1990s is comparable data from all of the agencies, to help Congress maintain a well-rounded view of federally supported research (for a summary, see table 8-9).

Table 8-7—Assessment of the Department of Energy's (DOE) Basic Energy Sciences Program: 1982

Objective	Assess the quality of research and performers Estimate the impact of the research on DOE mission Determine program balance Test appropriateness of DOE support
Evaluation questions	Specific scientific problem Research design Findings (past, current, expected) Impact on DOE missions
Methods and data	Ex post peer review Site visits Publication and citation counts Matching peer review (160 reviewers) and bibliometric data Stratified random sample of 125 projects (10 percent of total portfolio worth $250 million)
Recognized constraints	Reviewer variability (no random assignment of reviewers) Sample size too small
Outcome	60 percent of projects high overall quality 10 percent of projects exceptional 10 percent low quality
Costs and duration	$700,000-$800,000 Months to complete

SOURCE: U.S. Department of Energy, Office of Energy Research, Office of Program Analysis, *An Assessment of the Basic Energy Sciences Program*, DOE/ER-0123 (Washington, DC: 1982).

This chapter has outlined specific areas in which useful data could be compiled. Specific examples of data on research expenditures, personnel, the research process, and the outcomes of research were detailed. The *second priority* are data presented in forms that are instructive at disaggregated levels of

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[76] Some projects that were originally funded could have been rejected in hindsight. Likewise, some projects that were originally rejected probably could have delivered reasonable quality. The only way to estimate the quality of projects an agency rejects for support is to trace its history (which requires the cooperation of agencies and investigators). By examining samples of rejected projects funded by others, some notion of the imperfections of a selection process that led to unwarranted rejection may be obtained. Similarly, how does an agency, or the relevant program within it, determine that a funded project did not meet its stated objectives?

[77] For other examples, see National Academy of Sciences, op. cit., footnote 8, app. C.

[78] See J. Jeffrey Franklin, "Selectivity in Funding: Evaluation of Research in Australia," *Prometheus*, vol. 6, June 1988, pp. 34-60. The evaluation of an agency *program* would require far more than information on the projects it supports. Rather, questions of implementation—effectiveness and efficiency of decisions, and of the program personnel who make them—would dominate. In short, project evaluations aggregated to the program level would estimate the caliber of researcher performance more than success in administering the program. See Eleanor Chelimsky, "Expanding GAO's Capabilities in Program Evaluation," *The GAO Journal*, winter/spring 1990, pp. 43-52.

Table 8-8—Dimensions of Agency Research Evaluations

Purpose/research question	For example, to fund or not to fund, comparative project performance, extent of contribution to program missions/goals.
Definitions/criteria	For example, quality, priority, cost-effectiveness, innovativeness, success, accountability, impact, productivity, knowledge, growth.
Units of analysis	For example, institute, division, branch/center, program, project, individual, team, publications, citations, awards, rates of change, adoption/diffusion.
Outcomes	Process v. product, form of research v. content and outputs, cost per-outcome unit, qualitative v. quantitative.
Time horizon	Duration of award, short- v. long-term contribution, continuity/culmination v. new direction.
User audience	Well defined v. fuzzy, disciplinary v. multidisciplinary, knowledge- v. problem-oriented.

SOURCE: D.E. Chubin, "Designing Research Program Evaluations: A Science Studies Approach," *Science and Public Policy*, vol. 14, No. 2, April 1987, p. 85.

decisionmaking. In particular, data could be presented to make suitable comparisons and to gauge relative trends (i.e., as indicators of science and technology activity).[79] New indicators, grounded in the tradition of the SEI volumes and extramural research on research, are needed to monitor changes in the Federal research system.[80]

Finally, evaluation techniques of research investments in specific programs and projects were revisited. OTA finds that research evaluation techniques cannot replace mature judgment by policymakers. However, specific evaluation tools, such as bibliometrics and project portfolio analysis, could be further explored. A *third priority* is ongoing project evaluation, which could keep agencies alert to changes in research performance, augment program manager judgments about performers and projects, and serve to improve overall program effectiveness.

In summary, one of the functions of analysis is to raise questions about the information that decisionmakers are currently using to assess their advantages and disadvantages, and to define a richer menu of options. Much information could be collected on the Federal research system to map trends at different levels of aggregation and units of analysis for different users.[81]

However, the existence of data does not ensure its utility, for many policy issues cannot be addressed by additional descriptive information. In particular, external criteria involving the utility of research or impact on objectives can be more persuasive and salient to specific policy decisions. Depending on one's perspective and scope of responsibility, data on budgets, agencies, initiatives, performers, and outcomes can nevertheless clarify understanding of the evolving research system.[82]

This information, however, is not cost-free; nor is the organization for retrieving and distilling it. Congress could consider expanding agency resources to streamline collection and analysis of baseline data. NSF, working in concert with OSTP and OMB, could coordinate and reinforce this national data function, and organizations outside of

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[79] For example, the Engineering Manpower Commission that assembles, analyzes, and disseminates engineering enrollment and degree figures for the American Association of Engineering Societies recently remarked: "There is an old gag among survey researchers that when faced with a choice between consistency and the truth, one should always opt for consistency. When the product of the research is time series data that readers may track for years, the virtues of consistency become especially obvious." See "Consistency Versus Relevance: EMC Changes a Statistic," *Engineering Manpower Bulletin*, June 1990, p. 1. In other words, supplementing a time series with new measures without destroying the continuity of the series is also a virtue.

[80] Quantitative data will not suffice. Information on the contexts in which research is performed, and characteristics of the performers individually and collectively, will provide clues as to how the numbers can be interpreted and perhaps acted on. For example, see Daniel T. Layzell, "Most Research on Higher Education Is Stale, Irrelevant, and of Little Use to Policymakers," *The Chronicle of Higher Education*, vol. 37, No. 8, Oct. 24, 1990, pp. B1, B3.

[81] Three decades after historian Derek de Solla Price called for a full-blown "science of science," the policy potential of "research on research," as illustrated in this chapter, has only begun to be exploited. Price's vision is introduced in *Science Since Babylon* (New Haven, CT: Yale University Press, 1961) and *Little Science, Big Science*, op. cit., footnote 21, and elaborated in a series of analyses terminated by his death in 1984. For a retrospective, see Susan E. Cozzens, "Derek Price and the Paradigm of Science Policy," *Science, Technology, & Human Values*, vol. 13, Nos. 3 and 4, summer-autumn 1988, pp. 361-372.

[82] This leads OTA to suggest that the research agencies, especially the National Science Foundation and its policy programs, remain in close touch with analysts of the Federal research system. Keeping abreast of new measurement techniques and findings related to people, funding, and research activities—perhaps through extramural support—would be a modest but fruitful investment in extending inhouse capabilities and refining knowledge of federally sponsored research performance.

Table 8-9—Desired Data and Indicators on the Federal Research System

Category	Description	Method	Primary users Congress	Agencies	OMB	OSTP
Agency funding allocation method	Funding within and across fields and agencies Cross-agency information on proposal submissions and awards, research costs, and the size and distribution of the research work force supported	Agency data collection (and FCCSET)	X		X	X
Research expenditures	Research expenditures in academia, and Federal and industrial laboratories, centers, and university-industry collaborations Agency allocations of costs within research project budgets, by field Megaproject expenditures: their components, evolution over time, and construction and operating costs	Agency data collection	X	X	X	
Research work force	Size and how much is federally funded Size and composition of research groups	Lead agency survey	X	X		X
Research process	Time commitments of researchers Patterns of communication among researchers Equipment needs across fields (including the fate of old equipment) Requirements for new hires in research positions	Lead agency survey; onsite studies		X		
Outcome measures	Citation impacts for institutions and sets of institutions International collaborations in research areas Research-technology interface, e.g., university/ industry collaboration New production functions and quantitative project selection measures Comparison between earmarked and merit-reviewed project outcomes Evaluation of research projects/programs	Bibliometrics; surveys of industry and academia	X	X		X
Indicators	Proposal success rate, PI success rate, proposal pressure rates, flexibility and continuity of support rates, project award and duration rate, active research community and production unit indices	Agency analysis	X	X		X

KEY: OMB=Office of Management and Budget; OSTP=Office of Science and Technology Policy; FCCSET=Federal Coordinating Council for Science, Engineering, and Technology; PI=principal investigator.

SOURCE: Office of Technology Assessment, 1991.

the government, e.g., NRC and AAAS, could also play critical roles. Refining the measurement process could help to quantify existing opportunities and problems, and pinpoint previously uncovered ones, greatly enhancing research decisionmaking at all levels of the Federal Government.

APPENDIXES

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APPENDIX A

Major Legislation Enacted Since 1975 Affecting U.S. Research and Development

Number and date	Title	Important aspects
Public Law 94-282 May 11, 1976	National Science and Technology Policy and Organization Act	Called for the development of a national science and technology policy, and a national science and technology base. Created the Office of Science and Technology Policy (OSTP) in the Executive Office of the President (EOP) in order to advise the President on science and technology, including budget issues, and to assess the Federal effort in science and technology.
Public Law 95-91 Aug. 4, 1977	Department of Energy Organization Act	Created the Department of Energy, transferring all the duties of the Energy Research and Development Administration to the Department of Energy.
Public Law 95-367 Sept. 17, 1978	National Climate Program Act	Designed to coordinate climate research among the various research agencies, this act called for a heightened effort in climate research and defined the roles of the different agencies who do the research.
Public Law 96-479 Oct. 21, 1980	Materials Policy Research and Development Act of 1980	Required the President to formulate a national materials policy and submit a plan to Congress, addressing coordination in the executive branch and assessment of the economic, industrial, and national security needs regarding materials policy.
Public Law 96-480 Oct. 21, 1980	Stevenson-Wydler Technology Innovation Act of 1979	Created to promote technological innovation, this act established an Office of Industrial Technology in the Department of Commerce, and it mandated technology transfer from the Federal laboratories to the private sector.
Public Law 97-34 Aug. 13, 1981	Economic Recovery Tax Act of 1981	Established various tax breaks for research and development (R&D) expenditures, including a deduction for charitable contributions of R&D equipment to universities.
Public Law 97-219 July 22, 1982	Small Business Innovation Research Act	Aimed at strengthening the role of small firms in the performance of federally funded R&D, this act required all agencies with large extramural R&D budgets to set aside 5 percent of their budget (over 4 years) for the Small Business Innovation Research (SBIR) program.
Public Law 98-373 June 31, 1984	National Materials and Minerals Policy, Research and Development Act	Created the National Critical Materials Council in EOP to coordinate Federal materials R&D programs.
Public Law 98-462 Oct. 11, 1984	National Cooperative Research Act of 1984	In order to stimulate industrial R&D, this act promotes more joint ventures on research projects as it limits the effect of the antitrust laws in such cases. It also reimburses companies for legal costs associated with frivolous antitrust suits brought against them.
Public Law 99-502 Oct. 20, 1986	Federal Technology Transfer Act of 1986	Amended the Stevenson-Wydler Act to allow government-operated Federal laboratories to enter into cooperative R&D agreements, and established the Federal Laboratories Consortium for Technology Transfer.
Public Law 100-418 Aug. 23, 1988	Omnibus Trade and Competitiveness Act	Included the Training Technology Transfer Act and the Technology Competitiveness Act, as well as measures to support semiconductor R&D and to protect intellectual property rights.
Public Law 100-697 Nov. 19, 1988	Superconductivity and Competitiveness Act	Mandated a 5-year National Action Plan on Superconductivity R&D by OSTP, as well as an annual report updating Congress on the implementation of the plan.
Public Law 101-189 Nov. 29, 1989	National Competitiveness Technology Transfer Act of 1989	Part of a Department of Defense authorization bill, this act amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.

Major Legislation Enacted Since 1975 Affecting U.S. Research and Development—Continued

Number and date	Title	Important aspects
Public Law 101-239 Dec. 19, 1989	Omnibus Budget Reconciliation Act of 1989	Extended the R&D tax credit for another 9 months.
Public Law 101-508 Nov. 5, 1990	Omnibus Budget Reconciliation Act of 1990	Extended the R&D tax credit for 1 more year.
Public Law 101-589 Nov. 16, 1990	Excellence in Mathematics, Science and Engineering Education Act of 1990	Aimed at improving mathematics, science, and engineering skills, this comprehensive act authorized various programs focusing on elementary, secondary, and higher education, including programs promoting the use of technology in education.
Public Law 101-606 Nov. 16, 1990	National Global Change Research Act of 1990	Amended the National Science and Technology Policy, Organization and Priorities Act of 1976 to provide for a national plan to improve scientific understanding of the Earth system and the effect of changes in that system on climate and human well being.

SOURCES: U.S. Congress, House Committee on Science and Technology, *A History of Science Policy in the United States, 1940-1985*, prepared for the Task Force on Science Policy (Washington, DC: U.S. Government Printing Office, 1986); Congressional Research Service, Science Policy Research Division, *Statutory Provisions Related to Federal Research and Development*, prepared for the House Committee on Science and Technology, Subcommittee on Domestic and International Scientific Planning and Analysis (Washington, DC: U.S. Government Printing Office, 1976); and Office of Technology Assessment, 1991.

The Top 100 Institutions Ranked by Amount of Federal R&D Funding Received: Fiscal Year 1989

Rank	Institution	Dollars (in thousands)
1.	Stanford University, CA	238,650
2.	Massachusetts Institute of Technology	215,140
3.	University of Washington	182,453
4.	University of Michigan	174,875
5.	University of California, San Diego	171,479
6.	University of Wisconsin, Madison	169,452
7.	The Johns Hopkins University, MD	168,184
8.	University of California, San Francisco	159,906
9.	University of California, Los Angeles	159,002
10.	Cornell University, NY	157,984
	Total, top 10 institutions	*1,797,125*
11.	Columbia University, NY	146,712
12.	Harvard University, MA	143,451
13.	Yale University, CT	138,835
14.	University of Minnesota	132,880
15.	University of California, Berkeley	124,371
16.	University of Pennsylvania	123,810
17.	University of Southern California	119,005
18.	Pennsylvania State University	114,646
19.	University of Illinois, Urbana	114,398
20.	University of Colorado	109,145
	Total, top 20 institutions	*3,064,378*
21.	University of Rochester, NY	101,049
22.	Duke University, NC	99,036
23.	Georgia Institute of Technology	98,048
24.	Washington University, MO	96,829
25.	University of Texas, Austin	94,311
26.	Texas A & M University	93,584
27.	University of North Carolina, Chapel Hill	93,280
28.	University of Chicago, IL	90,459
29	California Institute of Technology	84,167
30.	University of Pittsburgh, PA	81,217
	Total, top 30 institutions	*3,996,358*
31.	New York University	81,143
32.	University of Arizona	80,533
33.	Ohio State University	75,484
34.	University of Iowa	74,217
35.	University of California, Davis	72,718
36.	Baylor College of Medicine, TX	69,336
37.	Case Western Reserve University, OH	68,632
38.	University of Alabama, Birmingham	68,204
39.	Carnegie-Mellon University, PA	65,079
40.	SUNY at Buffalo, NY	64,453
	Total, top 40 institutions	*4,716,211*
41.	Woods Hole Oceanographic Institute, MA	64,333
42.	Purdue University, IN	63,979
43.	University of Miami, FL	63,101
44.	University of Utah	61,819
45.	University of Florida	60,731
46.	University of Maryland, College Park	58,924
47.	Indiana University	58,334

Continued on next page

Rank	Institution	Dollars (in thousands)
48.	Yeshiva University, NY	58,224
49.	University of Tennessee System	57,763
50.	Northwestern University, IL	57,510
	Total, top 50 institutions	***5,320,929***
51.	University of Massachusetts	56,505
52.	Boston University, MA	56,402
53.	Vanderbilt University, TN	56,151
54.	Michigan State University	51,741
55.	University of Texas SW Medical Center, Dallas	51,254
56.	University of Virginia	51,214
57.	SUNY at Stony Brook, NY	49,726
58.	Oregon State University	49,112
59.	Princeton University, NJ	47,176
60.	Colorado State University	46,572
	Total, top 60 institutions	***5,836,782***
61.	Emory University, GA	46,497
62.	University of California, Irvine	46,492
63.	University of Connecticut	46,184
64.	New Mexico State University	45,660
65.	University of Illinois, Chicago	43,288
66.	University of Georgia	42,797
67.	Utah State University	42,449
68.	Rockefeller University, NY	41,192
69.	Tufts University, MA	40,771
70.	University of Cincinnati, OH	40,598
	Total, top 70 institutions	***6,272,710***
71.	University of Hawaii, Manoa	40,574
72.	Louisiana State University	40,114
73.	University of California, Santa Barbara	39,227
74.	Virginia Polytechnic Institute and State University	38,597
75.	North Carolina State University, Raleigh	37,783
76.	Georgetown University, DC	37,351
77.	CUNY Mt. Sinai School of Medicine, NY	37,233
78.	University of Maryland, Baltimore Professional Schools	35,970
79.	Rutgers University, NJ	35,896
80.	Brown University, RI	34,506
	Total, top 80 institutions	***6,649,961***
81.	Virginia Commonwealth University	30,078
82.	University of Texas Health Science Center, Houston	29,500
83.	University of Texas Health Science Center, San Antonio	29,324
84.	University of Texas M.D. Anderson Cancer Center	28,992
85.	Iowa State University	28,895
86.	University of Vermont and State Agriculture College	28,535
87.	Wake Forest University, NC	28,511
88.	Wayne State University, MI	28,167
89.	University of Medicine and Dentistry of New Jersey	27,983
90.	Dartmouth College, NH	27,222
	Total, top 90 institutions	***6,937,168***
91.	University of Kentucky	27,010
92.	University of Alaska, Fairbanks	26,659
93.	University of Dayton, OH	26,650
94.	University of South Florida	26,576

Rank	Institution	Dollars (in thousands)
95.	University of Kansas	26,420
96.	University of Nebraska, Lincoln	25,803
97.	Temple University, PA	25,232
98.	George Washington University, DC	25,220
99.	Florida State University	24,897
100.	Oregon Health Sciences University	24,162
	Total, top 100 institutions	***7,195,797***
	Total, all other sampled institutions	***1,354,669***
	Total, all institutions	***8,550,466***

NOTE: The Johns Hopkins University total does not include $422 million for the Applied Physics Laboratory. Also, 95 of the 100 institutions in the fiscal year 1989 top 100 were also in the fiscal year 1988 list. The concentration/dispersion of funding is identical in the 2 years.

SOURCE: National Science Foundation, *Academic Science/Engineering: R&D Funds—Fiscal Year 1989* (Washington, DC: forthcoming 1991), table B-35.

APPENDIX C

Funding Allocation in Six Federal Research Agencies[1]

National Institutes of Health

The primary review bodies for grant applications at the National Institutes of Health (NIH) are the study sections, of which there are over 90. Initially, all proposals go to the Division of Research Grants (DRG), which assigns each to a study section for an initial review and an institute for second level review. A grantee can request, but not designate, an institute; an institute can request that a grant be directed its way, but DRG has the right to overrule that request. Grant applications are classified according to type, such as new, competing continuation (renewal), and supplemental applications, and according to activities, such as regular research projects, conferences, centers, and fellowships. Last year DRG received over 30,000 applications.

Biennially each institute provides DRG with referral guidelines. The referral guidelines for all institutes are circulated and overlaps noted and negotiated through memoranda of understanding. Overlaps can usually be resolved in this manner. Most often, the issue then goes to the institute directors involved for a final decision. Grants in the areas of dispute can be assigned primarily and secondarily to the participating institutes or there may be a decision to send the grant to more than one institute for dual funding.

Study sections meet several times a year to review applications. Each proposal is discussed individually and recommendations are determined by majority vote of the members. If the application is recommended for approval, each member votes privately, assigning a priority rating from one for outstanding to five for acceptable. A priority score for an application is determined by averaging the individual ratings and multiplying by 100. To deal with the diversity of rating behavior among study sections and because of priority score "creep" (a tendency for scores to get better as reviewers realize that only the very best scores will allow a proposal to be funded), a percentile rank is now calculated for each score. The percentile represents the relative position or rank of each priority score among the scores assigned by the study section at its last three meetings. The lower the numerical value of the priority score or percentile, the better the application. Funding units designate an approximate percentile "payline," a priority score below which applications will not be funded.

After a grant has been through review by the study section, it enters a second level of review by the statutorily mandated National Advisory Council or Board of the institute. The councils and boards are comprised of scientists and lay representatives. They consider the percentiles assigned by the study sections and review grants for their relevancy to the institute's programs and priorities. Councils can choose not to concur with a study section approval based on program or policy considerations. However, they cannot reverse a disapproval action when their decision is based on scientific and technical merit only.

The award rate is the proportion of applications recommended for approval that are actually funded. In 1989, the overall award rate at NIH was 29.4 percent. The success rate is the proportion of reviewed applications that are actually awarded. In 1989, the overall success rate was 27.5 percent. In 1990, the award rate was 33 percent for competing renewals at the National Institute of General Medical Sciences (NIGMS), 14 percent for new applications, and between 12 and 15 percent for first-time applications. NIGMS budgets minority and training programs separately, thereby removing them from the same level of competition for limited resources (although each program is competitive in its own right).

At NIGMS, nearly 3,000 grant proposals are received each year. DRG study sections review the grants for scientific merit and amount requested. They then send their recommendations to the council for concurrence. Most often the council will approve blocks of grants. If rejected applicants wish to appeal they can submit rebuttals. In this case, NIGMS staff then submit their reply with the rebuttal to council. They can either support the study section decision or the rebuttal. More often than not, the council will concur with staff.

There has been a perception that the workload requirements associated with membership on study sections are an impediment for recruiting members. A 1989 review of study section workload showed that the average workload had actually gone down between 1980 and 1988, in part, because more study sections had been formed. In 1980, there were about 70 study sections. In 1988, there were 90. Still, the average study section member spends 45 days each year preparing for and attending meetings. This does not include site visits or mail reviews. The average tenure of service is 4 years. The NIH peer review system has been criticized for repeatedly using the same individuals on study sections. In fact, only 13 percent of reviewers are reappointed.

Some managers feel the payline has become inflexible and creates too much of a focal point for micromanagement. For example, if a program chooses to go below the payline and fund an exceptional grant, rejected applicants who came in above the payline have been known to request intervention by their representatives in Congress. The program and the institute must then respond to congressional inquiries and justify their decision. Some managers feel that this creates a disincentive for program managers to ignore the payline occasionally when considering innovative research. Some policies have been created to allow flexibility around the payline to fund young investigators and other groups.

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[1] This appendix is based on OTA interviews, spring-summer 1990.

However, every institute has an exception process for funding. Generally about 10 percent of the research budget can be used for exceptions or for applications below the payline that are cutting edge and, in the eyes of staff, deserve to be funded because of high program relevance. At the National Cancer Institute, for example, each division takes its exceptions to the director, where they are put in priority order and then compete for institute resources with the executive committee as final arbiter.

Department of Defense

The Department of Defense (DOD) solicits proposals through Broad Agency Announcements, which detail the interests of the services, the Defense Advanced Research Projects Agency (DARPA), or the Strategic Defense Initiative Organization (SDIO) research program. Program managers are allowed much latitude in funding decisions, and their performance is judged by the impact of the research program on issues of defense interest. External peer review may be used, but only in an advisory capacity. In general, inhouse review will suffice and laboratory personnel are often integral to this review process.

Army

Of the 6.1, 6.2, and 6.3A budget categories, the Army distributed 15 percent to basic research (6.1), 46 percent to applied research (6.2), and 39 percent in the early stages of development (6.3A). Within the 6.1 budget (fiscal year 1989), the Army laboratories received 68 percent, extramural single principal investigator grants accounted for 21 percent,[2] Centers of Excellence encompassed 6 percent, and inhouse laboratory independent research received the final 5 percent.

Within the Army, the 6.1 budget is disbursed by the Army Research Office (ARO), Medical Commands, and institutes such as the Army Research Institute for the Behavioral and Social Sciences. In addition, each laboratory, institute, or center has its own 6.1 monies. Through the tri-service University Research Initiative program, the Army also sponsors 12 centers in 10 research areas. In addition, the Army sponsors seven of its own Centers of Excellence.

Army Research Office—Until 1985, ARO did not solicit proposals directly. ARO has a tradition of supporting single investigators over long periods of time. ARO feels that this stable funding environment produces highly creative research, both because the investigator has more time to devote to research and because stable funds are sought by the scientific community, and so competition is fierce.

Medical Research and Development Command (MR&DC)—Medical research needs are addressed by the nine laboratories of MR&DC and monies are allocated between them. The largest, with 90 percent of the technology base funds, is the Walter Reed Medical Center. Walter Reed employs 1,100 scientists of which 600 are in the Institute for Research. About one-half are uniformed and the other one-half are civilian.

Army Research Institute for the Behavioral and Social Sciences—Research proposals are reviewed by the Basic Research Office (BRO), the laboratories, and often external reviewers. They are rated on five factors: 1) scientific significance, 2) potential Army relevance, 3) technical merit, 4) quality of executing personnel, and 5) cost realism. Contracts and grants are awarded on the basis of this inhouse, and partially external, review. Also, an inhouse review committee will examine annually all of the contracts and grants awarded in each program area. Universities receive 80 to 90 percent of the available grant and contract funds from BRO. Profitmaking corporations receive another 10 to 15 percent and nonprofits receive the remaining 2 to 5 percent.

Laboratories—Research laboratories operate primarily on 6.2 and 6.3 funds, but 6.1 monies make up a small proportion of the funding. Funds are distributed to research groups through inhouse budgeting. Contracts are awarded at program manager discretion after substantial scientific review by inhouse personnel.[3]

Navy

Almost all Navy basic research money is disbursed by the Office of Naval Research (ONR), although many of the larger laboratories also have small 6.1 budgets to support basic research. As part of the Navy's investment strategy for research, ONR stresses that, while spending 60 percent of their funds on "evolutionary" research and 25 percent on research that is "closely associated with transition to the fleet,'' 15 percent of the funds are allocated to high-risk, but potentially high-payoff research. ONR also seeks to leverage funds from other departments and industry to boost research in its programs in civilian laboratory settings.

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[2] Note that the University Research Initiative (URI) funds are not included in these figures since URI is now funded by the Office of the Secretary of Defense.

[3] For details, see U.S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base*, OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, April 1989), especially chs. 1 and 3.

ONR divides its efforts into ''core'' and ''accelerated'' research initiatives. Core initiatives build on previous efforts with slight modifications in levels of funding from year to year. Two percent of the research program is set aside for core enhancements. Each directorate will compete annually for enhancement funds and will often solicit external reviewers. Accelerated Research Initiatives (ARIs) provide increased levels of support over 3 to 7 years. The average funding is about $1 to $2 million per year, and about 6 percent of the current research program is set aside for new ARIs. Directorates also compete annually for funding for their proposed ARIs and, as with core enhancements, will solicit both inhouse and external reviews. The core program represents about 70 percent of the total Navy research program and ARIs total about 30 percent.

Air Force

Before 1974, inhouse laboratories controlled the 6.1 monies for the Air Force. However, in 1974, the Air Force consolidated the direction of the 6.1 monies into one unit, the Air Force Office of Scientific Research (AFOSR). Each laboratory still has a portion of 6.1 monies, but the bulk are distributed by AFOSR. The laboratories compete for these funds along with universities and other performers.

New initiatives are usually begun with funds designated for new starts ($10 million in fiscal year 1990). Eighteen months before the start of a fiscal year, the program managers propose new initiatives. The seven directorates then compete for the funds. Each directorate is asked to bid for twice their ''fair share'' (or one-seventh) of the funds set aside. An extensive inhouse review process determines the awarding of funds. Eight to 10 projects are awarded at about $1 million each. AFOSR requires that at least 15 percent of the research portfolio for a directorate changes composition every year.

AFOSR had about 1,200 grants and contracts in fiscal year 1990 (about 900 grants and 300 contracts). Roughly 500 projects are initiated in a year, with an average duration of 2 to 3 years. AFOSR works with close to 220 universities, which receive over one-half of AFOSR funding. Laboratories receive 30 percent of AFOSR funds.[4]

DARPA and SDIO

Project managers are primarily responsible for the selection of contract and grant awards, and usually conduct inhouse reviews of proposals. DARPA does very little contracting itself. ONR, AFOSR, ARO, or other parts of DOD will administer the grant, often because the service is the ''customer'' for the project and will benefit from its results. This close working relationship of DARPA and SDIO with other parts of DOD facilitates the technology transfer of the project findings.

Although program managers determine the specific goals of a project, the development of these goals through the letting of contracts and grants is left to the agent in ONR, AFOSR, ARO, or some other part of DOD. (Examples of specific goals include development of a particular kind of focusing mirror or more efficient laser using a particular kind of technology.) Managers use whatever selection mechanism they normally use for grants and contracts.

National Aeronautics and Space Administration

Office of Space Science and Applications

The Office of Space Science and Applications has two primary means of soliciting research/contract proposals. *Announcements of Opportunity (AOs)* are solicited and awarded over the associate administrator's signature. They usually call for hardware and experiments for an upcoming flight mission, and are funded via contracts. They represent one-of-a-kind opportunities with substantial monetary commitment. The AO is also the primary means of selecting the team of scientists for a mission. These scientists will not necessarily work together, but their combined efforts will set the schedule for the mission.

An AO will state the criteria and the procedure for selecting successful candidates. Usually, each proposal will be reviewed by panels of peers to judge scientific merit. Further review by National Aeronautics and Space Administration (NASA) staff will weigh feasibility, management issues, and relevance to the mission. NASA also keeps the prerogative of splitting up a proposal to fund only part of it and of joining two or more investigative teams together. The division will then rank the proposals. The final decision is left to the associate administrator, as advised by the division. An oversight committee, chaired by the assistant associate administrator, checks the selection criteria for adherence to proper procedures and adequacy of documentation of the review process. In descending order of importance, NASA acknowledges the following criteria to rank proposals: 1) scientific merit, 2) relevance to the goals of the mission, 3) adequacy of the research methods, 4) feasibility within logistical constraints, 5) competence and experience of the investigators, and 6) fiscal and other support by the investigator's institution.

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[4] One cannot compare directly funding allocation between universities and laboratories, because university funds reflect roughly full costs including investigator salaries whereas laboratory scientist salaries are funded through another budget line.

Research Announcements (RAs) are released under the signature of the associate administrator with the division director as the selecting official. They are more modest in scope than an AO, and more specific in focus. Taken together, however, the RAs cover a broader range of topics. In some divisions, RAs solicit "guest" observers, who will use an apparatus after the original investigator's share of the time is up. Theory, archival research, and other disciplinary areas are also supported with RAs. Like an AO, RAs state what selection criteria and which procedure will be used to make awards. Funding is primarily through grants. This procedure is usually very similar to the one described for an AO.

In addition to AOs and RAs, NASA employs other funding mechanisms. For example, unsolicited proposals are encouraged. They are submitted to a peer review process that is very similar to the procedure outlined above for AOs. Also, discretionary money is available to the division director, which represents a small portion (often nearly 10 percent) of the research monies and is disbursed by a less formal procedure (sometimes with only internal review) for projects of higher risk or for specific needs not addressed through other selection methods. Discretionary money is also available to the program manager. It is often allocated for the use of old equipment and flight time on NASA planes, and for technology development in preparation for new mission proposals.

Each division has its own method of proposal review. In general, however, for every proposal for funds, the program managers select the peer reviewers. (Life Sciences contracts with the American Institute for Biological Sciences (AIBS) to provide all peer review panels for their solicited and unsolicited proposals. AIBS has similar contracts with other agencies and it provides a "back room" check on duplication of funding.) For a small ($100,000 to $200,000) grant, four to five reviews are solicited. For larger proposals, as many as eight may be requested. The reviews judge scientific merit and technical feasibility. Program relevance and all other factors are judged by the program manager. It is generally recognized that university reviewers give the most conservative reviews and this type of factor is taken into account.

Each proposal is graded from A to E. (At AIBS, each reviewer also gives a rating of how competent he or she is to judge the science contained in the proposal.) If a proposal receives four reviews with ratings equivalent to four As, or two Bs and two As, it will generally get funded. Anything below four Cs would have to be defended forcefully within the division. However, among the group of high scoring proposals, it is up to the program manager to pick and choose to best satisfy his or her programmatic goals. Occasionally, there is concern over what proportion of the money should go to universities and the rest to NASA laboratories and private think tanks.

Office of Aeronautics, Exploration and Technology (OAET)

In OAET headquarters and in its laboratories, there is less reliance on AOs and RAs and more use of Requests for Proposals (RFPs). All proposal review for OAET is done inhouse. Most of the small aeronautics research grants that do not involve "cutting metal" are performed by the three laboratories (Ames, Langley, and Lewis) that operate with primarily OAET aeronautical research funds; space technology research is performed throughout the centers. If the contract is large, it will be farmed out (primarily) to industry and a laboratory will oversee the contract. The laboratories produce specifications, ask for bidders, and then negotiate procurement. Roughly 50 percent of the total research and development funds in OAET stays in the laboratories, 30 percent goes to industry, and 20 percent to universities.

Department of Energy

The Department of Energy's (DOE) Office of Energy Research uses many of the same proposal review techniques as NASA and the offices of scientific research within DOD, with peer or inhouse review for scientific merit and final judgment by the program manager. However, all individual investigator proposals are solicited through Broad Agency Announcements.

The majority of basic research funds at DOE (two-thirds of the Office of Energy Research budget, for instance) are given to the laboratories. These expenditures are estimated for the budget request for DOE and are derived through an iterative process with DOE headquarters. In the defense portion of DOE, almost all of the research is done in intramural laboratories. The money is competed among them, using mostly inhouse review.

In the Conservation and Renewables Office and in many of the other applied research offices, research money is often allocated with an industrial cosponsor. Contracts, grants, and cooperative agreements are all used. The evaluation of industry contracts is regulated by Federal law and is similar to that used by DOD and NASA. For individual investigator and university grants, peer review for scientific merit generally occurs. Inhouse review is used, at the very least, to allocate monies.

National Science Foundation

Proposals are received by the Division of Administrative Services and are assigned to the appropriate National Science Foundation (NSF) program for evaluation. Most proposals are unsolicited, though a few are in response to specific Announcements or RFPs. The applications are then reviewed by the relevant program officer and sent out for peer review. Proposers and reviewers are invited to suggest reviewers. The program officer may convene a panel (ad hoc or standing) to review proposals or can rely on mail reviews, or both.[5] The program officer can solicit advice from advisory committees, review panels, or site visits before recommending final action. Recommendations are then sent to division directors for review and approval.

Proposals are funded on the basis of demonstrated research performer competence, intrinsic merit of the research, utility or relevance of the research, and the effect of the research on the infrastructure of science and engineering. The success rate for the agency, overall, is about 30 percent, but is as low as 14 percent in some areas, such as decision, risk, and management sciences.

The program officer has a fair amount of discretion in making awards recommendations. Typically, after receiving the reviews on all proposals (some programs process grants on a continuous basis, relying on mail review rather than panels), the manager will sit down with the reviews and the program budget, evaluate the area of science each proposal encompasses, consider how much money the investigator is getting from other sources, and then make the difficult allocation decisions.

Many program officers said they tend to give new investigators a break. Others said they like to help out smaller colleges. There is a specific program announcement called "Research in Undergraduate Institutions" that encourages proposals from nondoctoral departments at institutions that produced 20 or fewer Ph.D.s in science and engineering in the 2 years preceding the proposal. Targets are set for the amounts NSF funds each year in this area, and divisions must ensure that minimums are met. In some cases, a proposal might be consistent with areas deemed of high priority, but would not fare well in disciplinary program competitions.

This is a point in the process where the program officer can also participate in the agency goal of increasing awards to women and minorities. Most program managers interviewed consider this an important goal and make their best effort to fulfill it. However, it has created a new dilemma. Money given to young investigators, women, or minorities comes out of a pool that would normally be given to the highest scoring proposals, which may come from older, established scientists with lofty track records. Program managers have to make the difficult decision of denying grants to, or cutting the budgets of, known performers in order to create a more equitable allocation of funds. The increasing number of applications, stable funding, and the process of reviewing grants have strained the system, say some managers. The safeguards built into peer review consume a great deal of staff time.[6]

Forty percent of the scientific and technical staff of NSF is comprised of rotators on temporary assignment, normally of 1 to 3 years duration.[7] They bring direct knowledge of forefront research to the grants process. Many interviewees feel that this prevents NSF from becoming an entrenched, out-of-touch bureaucracy. Rotating staff, however, can disrupt continuity in certain research areas, as new grants managers have the potential influence to shift the focus of research every few years.

Department of Agriculture

Agricultural Research Service (ARS)

The proposal process at ARS is unique. It is essentially a negotiation process between National Program Staff (NPS) and ARS scientists. ARS scientists work with their regional directors to send ideas up to NPS program leaders. Meanwhile, NPS sets out its budget priorities. Once the administrator approves the plan for the upcoming year, proposals are sent forward to NPS staff. If NPS staff want to fund a project, they send the proposal out for external review. Proposals are only sent out for review *after* the decision has been made to fund them. The reviewers are not asked whether the project should be funded, but how to improve the technical quality of the research. This places an enormous amount of power in the hands of NPS.

Obviously, there is room for criticism of this system of ex post peer review. In 1986, the ARS administrator asked the Board on Agriculture of the National Research Council (NRC) to examine the project peer review system, assess its effectiveness, and recommend possible improvements. NRC found a lack of agreement and understanding among ARS staff regarding the purpose, use, and effect of the system. There also seemed to be inadequate understanding within ARS as to how the administrator balances and optimizes the dual objectives of scientific excellence and mission relevance, and how project peer review is used in the context of these objectives.

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[5] The National Science Foundation has recently instituted electronic proposal review panels. See National Science Foundation, *Electronic Proposal Review Panels: An Option for NSF Program Officers* (Washington, DC: forthcoming 1991).

[6] A forthcoming General Accounting Office report on peer review procedures found no evidence of sloppy practices at the National Science Foundation. Concerns were raised, however, about review processes at other agencies, especially the Department of Energy and the National Oceanic and Atmospheric Administration. See David P. Hamilton, "NSF Off the Hook," *Science*, vol. 251, Feb. 15, 1991, p. 733.

[7] National Science Foundation, *Report of the Merit Review Task Force*, NSF 90-113 (Washington, DC: Aug. 23, 1990), p. 9.

Recently, NSF changed its rules to allow ARS principal investigators to apply to NSF for grants. This can be done only when ARS investigators are affiliated with a university that becomes the primary recipient of the grant. ARS scientists also apply directly for other sources of outside funding support to supplement ongoing research. Most ARS scientists will apply for other grants to support postdoctorates or graduate students.

One might ask what motivates the ARS scientist. A government salary and the system of getting project money is noncompetitive. The annual performance evaluation motivates the ARS scientist to propose good projects and perform well. In ARS, it is the scientist that is peer reviewed, not the research. ARS uses a system comparable to tenure review whereby a scientist is scored by peers on the level and quality of his or her research. The scores determine GS level. If an individual is found to be slipping, that is, not contributing to the advancement of the field in a manner demonstrated in the past, he or she can be demoted.

Cooperative State Research Service (CSRS)

Special Grants—The scientific agenda and budget for special grants are often specified in the agriculture appropriation bill. When given discretion over the awards process, CSRS often institutes open competition with peer review for scientific merit. Otherwise the research agenda is negotiated with the participating institution. Within these institutions, there may be competition for money (run by the institution itself), but it is often decided informally.

Competitive Research Grants—The Competitive Research Grants Office (CRGO) allocates funds with peer review mechanisms that are very similar to those at NIH and NSF. Review panels, chosen by the program manager and associate program manager, judge the scientific merit of proposals and their relevance to the purpose of the grant program to rank order them. Proposals are funded in order until the program runs out of money, and proposals are rarely pulled out of rank.

A new, congressionally mandated experiment at CRGO limited indirect costs in research grants to 25 percent in fiscal year 1990 and 14 percent in fiscal year 1991. The U.S. Department of Agriculture implemented this policy in fiscal year 1990 and proposals are now negotiated under the new terms. Program managers projected that this ceiling would be useful in fiscal year 1990 (optimistic estimates said that it would save $3.5 million to be disbursed to other researchers). After the first few years, universities and other organizations are expected to bill directly for laboratory space and other items usually claimed under indirect costs, thereby recouping the funds.

Forest Service

Research Work Unit Descriptions (RWUDs), written by research groups within Forest Service research centers, charter work in a particular problem area. They usually prescribe a plan for a 5-year duration and often will build directly on previous work. Staffing needs are directly related to the RWUD. The station director has a large amount of discretion to choose projects at the RWU level, but the RWUDs are reviewed inhouse in the Washington office to provide balance in a nationally coordinated program.

APPENDIX D

Academic and Basic Research Decisionmaking in Other Countries[1]

Compared to the United States, other countries have implemented vastly different organizational structures for their research systems. OTA has surveyed research decisionmaking practices in nine countries, including the United Kingdom, the Federal Republic of Germany, France, Japan, the Netherlands, Sweden, Canada, Australia, and India. It is clear that the institutional structures of policymaking and funding are critical determinants of the way in which governments support basic research, and provide a powerful context to which any new methods of selection of basic research must be adapted.[2] The reasons for this influence are at least twofold.

First, institutional structures strongly reflect the particular political, economic, and, more generally, cultural history of a country. While there may be certain universality in science, this does not carry over to science policy. Thus, it is essential for any comparative study of international science policies to place them in the context of national culture.

A striking example of these contexts is the heterogeneity of different national research systems. As Ziman noted in the United Kingdom and the United States, the academic department—". . . a multi functional organizational entity responsible for all teaching, research and other activities in a broadly defined scientific discipline . . ."[3]—is the predominant form of scientific organization. In contrast, France with its Centre National de la Recherche Scientifique laboratories and Germany with its Max Planck Institutes have research institutes, staffed by full-time researchers working in a designated problem or disciplinary area, as the most common model of research organization.

Second, decisionmaking structures themselves reflect in part previous processes of selection of basic research. Some claim, for example, that:

> . . . the Big Sciences such as high-energy physics and astronomy, which were funded generously in the past are now, as a result, well represented on decision-making bodies. There has, therefore, been a tendency for early established sets of priorities and research interests to become "frozen in" the decisionmaking structure.[4]

In this section, the research systems in nine countries will be highlighted and their priority-setting mechanisms examined (see table D-1 for a summary). Unfortunately the only comparable figures on the funding of research are aggregated with development. Figure D-1 shows the United States, West Germany, and Japan with comparable total research and development (R&D) funding levels as a percent of GNP, but West Germany and Japan at much higher levels for nondefense R&D. The United Kingdom and France spend less on R&D in both categories. For ease of comparison to the United States, the focus of this appendix will be on academic research, the bulk of which is carried out in the national universities of each country.[5] Some generalizations about methods of priority setting will be drawn first between the nine foreign countries studied, and then applications to the U.S. research system will be discussed.

United Kingdom

Three main themes run through the United Kingdom's government support of civilian academic science: the importance of maintaining and enhancing quality in science, increasing the economic and social returns from science, and better management through greater concentration and selectivity of science activities. Strenuous efforts have been made to introduce new policies to achieve those objectives.

The government reviews its R&D funding annually, but there is no overall R&D budget. The system is highly decentralized and each academic department determines its own R&D programs in the light of its own policy objectives and priorities. Recent decisions to exclude the public funding of near-market research led to some

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[1] This appendix is based on Ron Johnston, University of Wollongong, Australia, "Project Selection Mechanisms: International Comparisons," OTA contractor report, July, 1990. Available through the National Technical Information Service, see app. F. The work on this contract was completed before East and West Germany united. Also see Leonard L. Lederman, "Science and Technology Policies and Priorities: A Comparative Analysis," *Science*, vol. 237, Sept. 4, 1987, pp. 1125-1133.

[2] "Institutional structures" refer to the bodies—often administrative agencies, advisory councils, and review panels—that implement policies for priority setting and funding in science.

[3] John Ziman, *Restructuring Academic Science* (London, England: Science Policy Support Group, 1989).

[4] J. Irvine and B. R. Martin, "What Direction for Basic Scientific Research," *Science and Technology Policy in the 1980s*, M. Gibbons and A. Udgaonkar (eds.) (Manchester, England: Manchester University Press, 1985).

[5] Except in Canada, where research is conducted in provincial universities.

Table D-1—Recent Approaches to More Selective Support of Basic Research

		Priority settting:		
Country/agency	Steering device	Method	Decisionmakers	Status
UK				
UFC	Selective core funding to universities	NA	NA	Government appointed
ABRC	Interdisciplinary Research Centers (1988)	Submissions and internal discussion	Panels	Appointed
SERC	Directorates (7 years) and Program (5 years)	Internal discussion	Council (peers and users)	Appointed
ESRC	Centres (5-15 years)	Internal discussion	Council (peers and users)	Appointed
FRG				
DFG	Priority programs	Bottom-up discussion	Researchers	Elected
MPG	Priority research areas institutes	Bottom-up discussion	Researchers	Elected
France				
MRT	Programmes mobilisateurs	Identification of generic technologies	CPE and department officials	Elected and appointed
CNRS	Annual strategic plans	Identification of leading researchers	Council peers and department officials	Elected and appointed
Japan				
Monbusho	Priority research areas (3-6 years)	Identification of areas of strong scientific opportunity and social need	Monbusho Science Council	Appointed
	Specially promoted research (5 years)	Selection of 2 key fields and program leader	Science Council	Appointed
Netherlands				
MES	Conditional funding of university research	NA	NA	Appointed
NWO	Second flow funding	Identification of future needs and priorities	RAWB (appointed) and NWO	Elected
Sweden				
Cabinet	Research policy bill	Wide consultation, symposia, reports over 2 years; and government departments, scientific societies, researchers	Effective consensus	NA
NFR	Consortia	Invitations to consortium of university departments to propose interdisciplinary programs	Council (appointed and elected)	Appointed and elected
FRN	Priority fields	Identification of societal problem, then elaboration of research needs and opportunities	Council and committees (research and users)	Appointed and elected
Canada				
ISTC	Decision framework for science and technology	Computation of agencies' research priorities, identifying strengths and gaps	ISTC	NA

Continued on next page

transitory increase in funds for research. However, the funding outlook has now dimmed.[6]

The major source of funds for academic research is the Department of Education and Science (DES). It provides general support for university teaching and research through the Universities Funding Council (UFC) and five research councils, in what is commonly referred to as the "science budget." The DES-supported research councils provide funds on a competitive basis to university researchers and in most cases maintain their own research centers. The research councils have a high degree of autonomy in establishing their own priorities and procedures. The Advisory Board of the Research Councils (ABRC) also plays an important role in advising DES on the overall budget and on the allocations to the five councils.

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[6] For example, see Jeremy Cherfas, "Deficits Trip U.K. Science Funding Agencies," *Science*, vol. 250, Dec. 14, 1990, pp. 1504-1505; and Peter Aldhous, "UK Nuclear Physicists Fear SERC's Cuts," *Nature*, vol. 349, Jan. 31, 1991, p. 357.

Table D-1—Recent Approaches to More Selective Support of Basic Research—Continued

		Priority settting:		
Country/agency	Steering device	Method	Decisionmakers	Status
NSERC	Strategic grants program	Identification of 30 themes in the 3 national priority areas by consultation, analysis, and workshops	Science Council of Canada	Appointed
SSHRC	Strategic research program	Biennial seminars and commissioned reviews	Council (department officials and researchers)	Appointed
Australia				
ARC	Priority research areas	Submissions consultation and internal discussion	Council (researchers)	Appointed
NH&MRC	Priority research fields	Internal discussion and consultation	Council (researchers) and panels	Appointed
India				
National Development Council	Five year Science and Technology Plan	Expert reports, consultation, draft reviews	Council (government officials)	NA
SERC	Thrust area programs	National exercise of working paper preparation, review, national seminar	Council and program advisory committees (scientific experts and government officials)	Appointed
	Intensification of research in high-priority areas scheme	Thrust area identification exercise	PACs	Appointed

KEY:
ABRC = Advisory Board of the Research Councils
ARC = Australian Research Council
CNRS = Centre National de la Recherche Scientifique (National Center of Scientific Research)
CPE = Centre de Prospective et Evaluative (Prospects and Evaluation Center)
DFG = Deutsche Forshungsgemeinschaft (German Research Society)
ESRC = Economic and Social Research Council
FRG = Federal Republic of Germany
FRN = Council for Planning and Coordination of Research
ISTC = Industry, Science and Technology Canada
MES = Ministry for Education and Science
Monbusho = Ministry of Education, Science, and Culture
MPG = Max Planck Gesellschaft (Max Planck Society)
MRT = Ministry of Research and Technology
NA = Not available
NFR = National Science Research Council
NH&MRC = National Health and Medical Research Council
NSERC = Natural Sciences and Engineering Research Council
NWO = Netherlands Organization for Scientific Research
PAC = Program Advisory Committee
RAWB = Science Policy Council of the Netherlands
SERC = Science and Engineering Research Council
SSHRC = Social Sciences and Humanities Research Council
UFC = Universities Funding Council
UK = United Kingdom

SOURCE: Ron Johnston, "Selection of Basic Research: An International Comparison," OTA contractor report, June 1990, table 3. Available through the National Technical Information Service, see app. F.

Recently UFC introduced a system of ranking academic departments on their research capability as part of the determination of support.[7] General University Funds are distributed by UFC, one component of which is for the support of research, though universities may use these funds for education as well. Since 1986, the formula to determine how much should be given to a department favors those institutions judged to have high-quality research. In 1989, UFC further ranked departments within universities on a scale of 1 to 5. The criteria used to determine ratings were: 1) publications, 2) success in obtaining research grants and support for students, 3) success in obtaining research contracts, and 4) the professional judgment of advisory group and panel members. There is considerable debate on the efficiency of this approach.[8]

ABRC has also initiated or encouraged a number of new procedures in the allocation of support for academic research. The first has been to increase the proportion of funding flowing to "directed programs" which have increased from 19 to 32 percent of the councils' grants since 1980. These are designed to help coherent programs of research in selected areas or to stimulate research in fields judged to require more effort in the national interest. The second initiative has been to increase the proportion of program grants, as opposed to project grants, from 15 percent in 1980 to 20 percent in 1989. Program grants are generally larger, support a bigger team of researchers, and last for a longer period (5 years) than project grants. Thirdly, in 1985, it recommended a set of six criteria to be adopted by the research councils in determining funding (excellence, applicability, timeliness, pervasiveness, sig-

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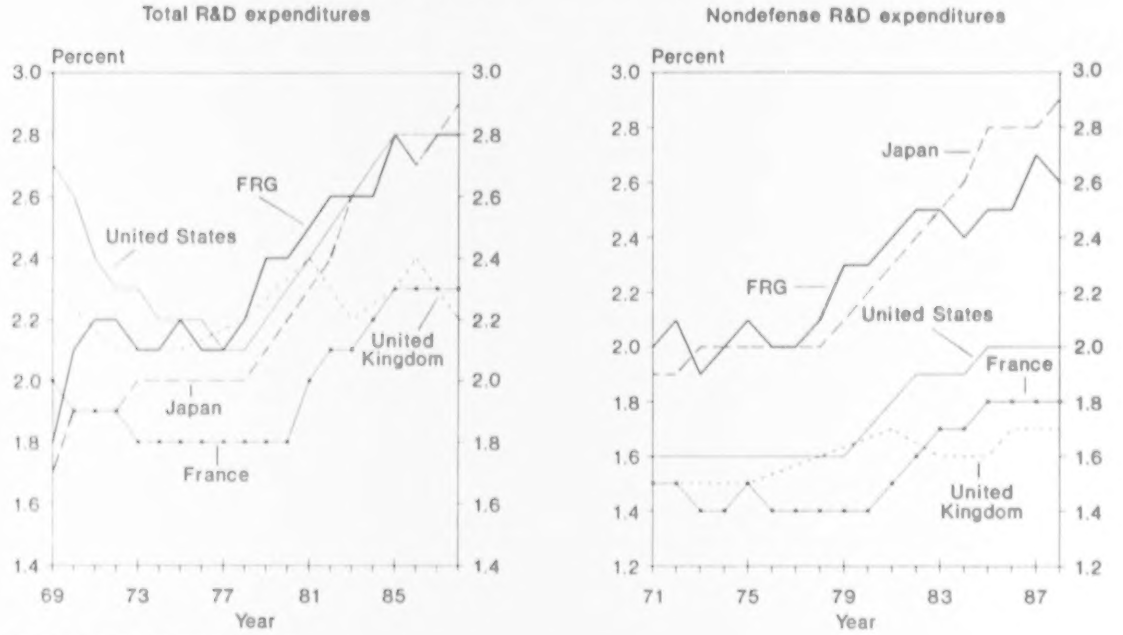
[7] See "British Science Indicators," *Outlook on Science Policy*, vol. 11, November 1989, pp. 112-113; and M.P. Carpenter et al., "Bibliometric Profiles for British Academic Institutions: An Experiment To Develop Research Output Indicators," *Scientometrics*, vol. 14, Nos. 3-4, 1988, pp. 213-233.

[8] See Peter Aldhous, "University Funding Plan Collapses in Chaos," *Nature*, vol. 348, Nov. 1, 1990, p. 3.

Figure D-1—R&D Expenditures as a Percent of Gross National Product, by Country


Total R&D expenditures

Nondefense R&D expenditures

KEY: FRG = Federal Republic of Germany.

SOURCE: National Science Foundation, *National Patterns of R&D Resources: 1990*, final report, NSF 90-316 (Washington, DC: 1990), tables B-18 and B-19.

nificance for education and training, and exploitability), which have been applied by some of the councils.

The most recent initiative, together with the research councils, UFC, and DES, has been the establishment of Interdisciplinary Research Centers (IRCs). Funded for 6 years, their objectives are: 1) greater concentration of research effort; 2) more interdisciplinary collaboration; 3) increased effort in areas of "strategic" science, i.e., important for economic progress; 4) stronger interface between strategic research in higher education and industry; 5) more positive and purposeful management of research within higher education; and 6) more effective collaboration between universities and the research councils in the deployment of research resources.

Thus, the general approach to academic research selection in the United Kingdom can be summarized by two statements: 1) there is an increasing degree of priority setting, the priorities emerging from interaction between peer review committees and various advisory bodies;[9] and 2) there is a move to concentrate research resources by provision of larger and longer grants to programs and centers.

Federal Republic of Germany

In contrast to the United Kingdom, the most striking feature of German science policy is the indirect influence of government, which funds virtually all academic research but accords significant autonomy to research-performing and research-promoting institutions.[10] The freedom of research is expressly established in the Federal German constitution. In this context, and that of a generous and growing budget for research, it is apparent that there is little expressed need for, and indeed some hostility to, notions of directed research or priority setting.

Research is performed primarily in three sets of institutions: the 50 universities, the 60 institutes of the Max Planck Gesellschaft (MPG), and the 13 national research centers. Decisionmaking about research project selection is largely made within the research institutions or by the Deutsche Forschungsgemeinschaft (DFG—the German Research Society).

DFG is the central, self-administering, academic research support organization (spanning basic, applied, and strategic research) in the Federal Republic of Germany. It receives its funds from the federal and state governments, and as the primary source of "drittmittel"—the additional funds for research—it exerts influence on the profile of research. The function of DFG resembles that of the research councils in the United Kingdom. It is organizationally independent of government, but financially dependent on it. It is a scientific society whose membership includes the universities, other research institutions such as the Max Planck institutes, seven of the national research centers, and prominent scientific associations. The president and senate are elected, as are the approximately 400 expert consultants who hold office for 3 years, to provide expert peer review.

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[9] Working Group on Peer Review, *Peer Review*, a report to the Advisory Board for the Research Councils (London, England: November 1990).

[10] This section has benefited from Leonard Lederman, Scientific and International Affairs Directorate, National Science Foundation, personal communication, December 1990.

DFG shapes the profile of German academic science from the bottom up, augmenting government funding of salaries, instrumentation, facilities, and MPG initiatives. The resistance to direction of research by DFG is clear: "DFG officials are determined that targeted funds should not exceed 10% of overall expenditure since this might give rise to renewed alarm about academic autonomy and flexibility."[11]

The functions of MPG are to undertake research in areas of particular importance, newly emerging areas, or where a concentration of effort is required. Its legal status is that of a private nonprofit organization despite most of its finance coming from the government. Proposals for new institutes are received each year and undergo an extensive evaluation process. Judgments are made by the MPG senate on scientific merit, fruitfulness, appropriateness to MPG (as opposed to universities), and the availability of an outstanding scientist to fill the position of leader. Once established, an institute is subject to review every 2 years by a visiting committee and every 7 years by a prestigious panel of overseas experts. Occasionally an institute is closed.

The national research centers were established as essentially big science institutes in fields such as nuclear, aviation, and space research where a large concentration of very expensive infrastructure was necessary. Some of these centers are now facing the challenge of missions completed or no longer relevant, and are seeking new orientations.

OTA concludes that basic research selection in the Federal Republic of Germany rests essentially on bottom-up proposal pressure and peer review. Priority setting is used mainly to achieve concentrations of effort through cooperative teams or centers. The unification of the former German Democratic Republic and the Federal Republic of Germany may offer opportunities of international importance for research, but it is too soon to tell.[12]

France

The French approach to decisionmaking for academic research, as for all areas of the economy and society, rests on a traditional commitment to centralized planning. In the area of research, the strong emphasis is on economic goals, and priority is given to industrial research.[13]

The Ministry of Research and Technology is responsible for recommending and implementing government policies in the field of science and technology, and for determining priorities for research, with the advice of the Research and Technology Council. The performance of basic research occurs primarily in the Center National de la Recherche Scientifique (CNRS) laboratories located alongside the universities and within the universities, which receive core funding from the Ministry of National Education and CNRS. CNRS maintains its own laboratories, independent of universities. The French system relies on block grants to the laboratories and research groups, rather than specific project grants to individual researchers. But there is growing academic criticism of CNRS's favored "inhouse" position as a research performer.

CNRS finances the entire range of academic research from the physical sciences to the humanities. Annual strategic plans are prepared, which rely as much on the identification of leading research individuals and groups as on promising areas of research. In addition, CNRS has conducted a range of prospective studies that feed into the planning process.[14]

The French Government has recently mounted a major initiative to promote the strategic application of foresight and evaluation to the national research system. A National Research Evaluation Committee (CNER) was established in response to the government's decision to institute the systematic periodical assessment of all research-performing institutions. This follows the experience of the National Evaluation Committee of the Universities, founded in 1985, which has assessed the research of 25 universities on a voluntary basis.

CNER is responsible for the evaluation of the organization and results of a national technological research and development policy. To achieve this goal, the committee ensures the periodic assessment of institutes, programs, and incentives of all kinds financed from the civilian technological R&D budget.

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[11] B.R. Martin and J. Irvine, *Research Foresight* (London, England: Frances Pinter, 1989), p. 80. Despite the pronouncement, targeted funds are suspected to exceed 10 percent.

[12] See Rolf H. Simen, "Research Landscape Requires Careful Gardeners: Science in Unified Germany—Experts' Opinions During Villa-Hugel Talks," *German Research Service Special Science Reports*, vol. 7, January 1991, pp. 11-13.

[13] For an overview of France's 24 research agencies, see "FAST Guide to French Government R&D," *French Advances in S&T*, vol. 4, No. 1, winter 1990-91, pp. 3-6.

[14] See Martin and Irvine, op. cit., footnote 11, pp. 47-50.

In summary, there is a strong emphasis on planning and direction of research toward technological objectives in the French research system.[15] The attempt is made within the universities to set basic research directions largely on the grounds of scientific excellence. However, within CNRS, scientific departments put forward proposals that are judged internally on grounds of merit and relationship to priority areas.

Japan

The dense population, a deep commitment to the values of the group, and the spiritual principles of Confucianism have produced a culture that emphasizes the values of harmony, respect, and decisionmaking by consensus, even if the process is protracted.[16] These values permeate the decisionmaking structures and procedures with respect to science.

Within the government, the Prime Minister's Office and its key policy body, the Council for Science and Technology (CST), exercises the highest level of control over the direction of scientific and technical research.[17] Four main government agencies in Japan support and target R&D: the Science and Technology Agency (STA); the Ministry of Agriculture, Forestry, and Fisheries; the Ministry of Education, Science, and Culture (Monbusho); and the Ministry of International Trade and Industry (MITI).

STA is responsible for the overall coordination of science policy among the different ministries and agencies. It is also responsible for big science and includes research institutes to fill this function.

While STA is the agency primarily responsible for basic research, MITI has had considerable influence over research policy in Japan through its emphasis on applied R&D. MITI runs 16 national research laboratories and develops research programs with industry. These programs are most often in technological areas in which Japanese industry is considered to be weak, into which no single company would enter alone, or which are for the public good and not necessarily commercially valuable. While MITI is most involved in raising the technological level of Japanese industries, this is small compared with STA's activities.[18]

Monbusho is responsible for the promotion of research across all fields and for the national university system. In formulating policies, Monbusho consults its science council, consisting of 27 eminent scholars whose names are put forward by the academic societies but appointed by the Minister. In addition to general research funds for divisions of university faculty, construction, and equipment monies, Monbusho has a new program in which the Science Council chooses a research field for priority funding (generally two a year).

The Science Council is a democratic body established by law as the representative body of Japanese scientists and engineers. It has the right to make recommendations directly to the government on the ways and means to promote science and technology. Among its major successes was the establishment of nine interuniversity research centers. However, in recent years its influence has waned in favor of CST. The role of CST in integrating and coordinating research has been considerably strengthened through the establishment of a Science and Technology Promotion Coordination Fund, which is used in part to support basic research in special priority fields designated by CST.

Thus, the essential process of research selection in Japan is through the time-honored mechanism of a committee of wise men. Priorities are established by this consensual process, involving varying degrees of interaction with an influence of academic researchers on the one hand and government officials on the other.[19]

Netherlands

The Dutch are among the leaders in formulating science policy in Europe and have carried its implementation much further than many other countries. The major emphasis of science and technology policy has been on a more effective planning and linking of strategic and applied research to national economic and social needs.

The Minister for Education and Science has recently produced a discussion document, "Towards a Science Policy for the Nineties." As a result, the government has once again decided to elevate science on the Dutch political agenda. The three major objectives for the 1990s are: 1) establishment of a more effective scientific basis for key societal functions; 2) achievement of an important role of research in the process of internationalization; and 3) the well-balanced development and application of science and technology to economic, social, and cultural needs.

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[15] See Remi Barre, "Strategic Processes and S&T Indicators: Towards a Key Role in R&D Management Systems," *The Research System in Transition*, S.E. Cozzens et al. (eds.) (Dordrecht, Holland: Kluwer, 1990), pp. 227-239. For the past 2 years, the Center for Technology Forecasting and Assessment in the Ministere de la Recherche et de la Technologie, in conjunction with the Commission of the European Communities, has published an *R&D Evaluation Newsletter*, which reports the results of research evaluation efforts throughout the world. Stressing evaluation has not overtly affected planning or resource allocation decisions.

[16] See Genevieve J. Knezo, "Japanese Basic Research Policies," *CRS Report for Congress* (Washington, DC: Congressional Research Service, Aug. 1, 1990).

[17] See Council for Science and Technology, Policy Committee, Prime Minister's Office, and Committee on Guidelines for Research Evaluation, *Basic View on Research Evaluation* (Tokyo, Japan: 1986).

[18] See Johnson Chalmers, *MITI and the Japanese Miracle* (Stanford, CA: Stanford University Press, 1982).

[19] See John Irvine et al., *Investing in the Future* (Worcester, England: Billings & Sons Ltd., 1990).

The independent Science Policy Council of the Netherlands (RAWB) is the central advisory body on science policy. It has had significant influence on priority setting and resource allocation through its reports on future needs and opportunities in particular fields. RAWB also undertakes assessments.

Basic research is performed essentially in the universities that are funded by the Ministry of Education and Science (which administers over one-half of the government R&D budget) and in the institutes established by the Netherlands Organization for Scientific Research (NWO). The latter also funds some research in universities.

Before the latter half of the 1970s, university research was largely considered in relation to educational policies, with particular emphasis placed on the close relationship between academic research and university teaching. Gradually there has been a shift in approach developed in the last decade or so, and academic research objectives are increasingly related to external economic and social requirements. The scope for effective planning and steering of the direction of university research in the context of science policy has been constrained in the past by the funding structures for university R&D. The Netherlands is now experimenting extensively with these structures and performance assessments.

A feature of policy in the last few years has been the move gradually to transfer responsibility for research from government departments to universities or to institutes operated by NWO. This represents one element in a developing strategy to reshape the existing national R&D system, which is widely seen as lacking the degree of integration and coherence that is needed if the country is to maintain an internationally competitive effort in key areas over the next decade.

In summary, the Dutch Government and universities have been particularly active over the past decade in reshaping their science and technology policy decisionmaking procedures and capabilities. While this effort has been directed to technology development, there has been some attention as well to methods of project selection for research. Experimentation with these methods has allowed new policy alternatives to emerge. In particular, these new methods allow more funds to be allocated on a competitive basis and in priority areas. The priorities are determined by traditional committee methods where scientific and government interests meet and negotiate from their own perspectives.

Sweden

There is a long tradition of extensive government involvement in decisionmaking in a range of research areas in Sweden, grounded in a lengthy process of consensus formation, planning, and evaluation. R&D has been strongly directed, particularly through the central establishment of priorities and funding levels every 3 years in a Government Research Policy Bill.

Policies are developed through an interactive process between funding agencies, departments with responsibility for R&D, and a group in the Cabinet Office, with overall responsibility vested in the latter. There is a strong bottom-up element in the decisionmaking process, which is set against the background of the Bill on Research. That this bill is programmed into the legislative process allows all the players to develop their initiatives in the period leading up to the consideration of the bill. Background studies, monitoring of overseas developments, and symposia that bring together representatives from academia, industry, and the government all form part of the process.

This extensive consultation and debate ensures that all interested parties have an opportunity to make their views known and that the community in general is committed to the areas and issues identified in the research bill. In the February 1990 bill, the priority areas were: 1) strengthening basic research in universities; and 2) increasing research in five target areas—environment, marine processes, public health, industrial safety, and cultural research.

Basic research, roughly one-quarter of Swedish R&D, is conducted almost entirely within universities—there is virtually no government research capacity. Three research councils play a major role in determining research areas and resource allocation: the Medical Research Council, the Natural Science Research Council, and Council for Research in the Humanities and Social Sciences. Each council has a large degree of autonomy. A fourth council, the Council for Planning and Coordination of Research, is not a "research council" per se. It assists in government research planning and coordination, public understanding and participation in this process, and the assessment of Swedish research capabilities.

Strong direction setting characterizes Swedish strategic research.[20] Less direction is given to basic research, but its priorities are affected through the connection to strategic initiatives. The 3-year research bill provides a strong framework for this connection.

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[20] See George Ferne, *Science and Technology in Scandinavia* (London, England: Longman, 1989). Not only is the research evaluation tradition strong (perhaps the strongest in Western Europe), but it also involves the participation of foreign scientists and much public discussion of decisions. See Michael Gibbons, Organisation for Economic Cooperation and Development, *Evaluation of Research in Sweden* (Manchester, England: University of Manchester Press, 1984).

Canada

Canadian science policy has been marked in the past decade by a high level of debate, conflict, and change. The major pressure for this change has been the heavy reliance of the Canadian economy on its resource-based industries and the recognition that such economies are becoming increasingly vulnerable and noncompetitive. Canada has a reputation for scientific excellence and long-established central government laboratories.

Canada is a federal system, with the special requirements for coordination that such a system implies. The higher education sector is funded almost entirely from taxes collected by the national government and allocated to the provincial governments.

There is a large set of advisory and decisionmaking bodies in the Canadian science and technology system. Three of the most important are: 1) the National Advisory Board on Science and Technology, which advises the Prime Minister on overall guidelines; 2) Industry, Science, and Technology Canada (ISTC), which coordinates industry and academic research; and 3) the Science Council of Canada (SCC), which provides independent advice on science and technology. SCC has been a long-time advocate of systematic research priority setting, and ISTC compiles the Decision Framework for Science and Technology, which requires departments and agencies responsible for R&D to prepare annual lists of priorities.

Nevertheless, while there has been a strong push toward linking research more effectively to national needs,[21] this has been resisted in the case of basic research. The overall framework of planning thus far impinges only indirectly on basic research.

Australia

Australia is in many respects similar to Canada, with its federal structure and its drive to broaden and deepen the technological intensity of its predominantly agricultural and minerals-reliant economic base. There is also a long tradition of commitment to internationally excellent research, with a particularly strong government research capability.

In recent years Australia has developed a sectoral model of science policy, with major R&D funding and performing responsibilities spread across a number of major departments. To overcome problems of fragmentation, a Coordination Committee of Science and Technology, made up of senior officials of the departments, has been appointed. In addition, the Prime Minister receives advice from the Science Council—composed of ministers, industrialists, and a minority of scientists, and the Australian Science and Technology Council—composed of appointed academics and industrialists.

With nearly 70 percent of research in the public sector, there has been a considerable emphasis on restructuring to give greater priority to strategic research directed to medium- and long-term industrial needs.[22] The universities, which are established under state legislation but funded by the federal government, are also under increasing pressure to serve national interests.

In Australia the principles and practice of priority setting have been effectively established for strategic and applied research.[23] As in Canada, planning for basic research has met with a degree of resistance from researchers and universities, who have seen it as a challenge to their autonomy. Hence, priorities have been applied to basic research only to a modest extent.

India

Science and technology (S&T) in India has grown under strong and sustained political support. Even before India became independent in 1947, the national leaders had recognized the role of S&T in national development. Nehru's vision of S&T came to be accepted as an instrument not only for industrial and economic development, but also for transforming a tradition-bound society into a progressive nation.[24]

In line with the concept of socialism, the state continues to be a strong supporter of S&T, providing 80 percent of the funds for all R&D. It also shoulders the responsibility for directly guiding and planning the activities of an extensive network of S&T institutions. R&D activities are carried out by institutions that come under central and state government departments, industrial units, professional bodies, and by university-type structures. The universities carry out research and provide human resources for research institutions.[25]

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[21] See Baha Abu-Laban (ed.), *University Research and the Future of Canada* (Ottawa, Canada: University of Ottawa Press, 1988).

[22] J. Ford, "Australia Tilts Its R&D Towards Industry," *New Scientist*, vol. 116, No. 1580, 1987, p. 19.

[23] M. Dodgson, "National Policies—Research and Technology Policy in Australia: Legitimacy in Intervention," *Science and Public Policy*, vol. 16, No. 3, June 1989, pp. 159-166; and Australian Science and Technology Council, *Setting Directions for Australian Research* (Canberra, Australia: Australian Government Publishing Service, June 1990).

[24] A. Jain, "Science and Technology Policies in India," *Science Policies in International Perspective: The Experience of India and the Netherlands*, P.J. Lavakare and J.G. Waardenburg (eds.) (London, England: Frances Printer, 1989), p. 139.

Though the basic orientation of national S&T policy has been, and still is, to treat S&T as an integral part of socioeconomic development, there have been several changes in organization and planning strategies over the years. For example, the Industrial Policy Resolution of 1948 allowed considerable scope for introducing foreign technology into the country, but had little influence on linking the imports with the indigenous S&T structure. Under this policy ethos, an extensive government-dominated research infrastructure emerged during the next 20 years, almost undisturbed by economic developments. Priorities in S&T were set by the leaders of science, but efforts at formulating policy instruments and plans to couple S&T capabilities with requirements of agriculture, industry, and other economic sectors were weak.

The Prime Minister of India has always been the minister-in-charge for S&T, with three advisory mechanisms at his or her disposal: the scientific adviser, the adviser for technology missions, and an independent 11-member Science Advisory Council. India's planned approach for the development of S&T became part of the national planning exercise. The Planning Commission plays a central role in formulating the national S&T 5-year plan with the involvement of scientists, technologists, and representatives of concerned agencies and departments.

International Comparisons

From the discussion above, it is clear that the methods used for selecting basic research for government support vary greatly among countries. For example, Canada and Australia are pluralistic and strongly averse to directing research initiatives, while there is growing pressure in the United Kingdom for priorities to be determined centrally, a tradition long observed in France.

OTA finds that in every one of the nine nations examined there has been a substantial development of methods for effective targeting of strategic and applied research to national economic needs. This push for greater economic payoff from research has also led some countries to increase their proportions of strategic basic research at the expense of undirected basic research. There has also been considerable experimentation with new methods to identify strategic avenues of high promise. However, the development and application of new selection methods for basic research has generally been approached with considerable caution by research funding agencies and been met with considerable opposition from researchers. Also, there is no evidence that government targeting of research has increased economic payoffs.[26]

Another finding is that the extent of direction of basic research is apparently directly related to the need to do so—the most important factor is the availability of resources to support basic research. In countries like Germany and Japan where there appears to be little shortage of funds to support basic research, there is no great enthusiasm for more central direction of research—even though both countries have elaborate mechanisms for targeting strategic research and linking it to industrial and commercial opportunities. At the other extreme, countries suffering a significant squeeze on funds available for basic research, and who have been less successful in establishing mechanisms for pursuing an adequate level of strategic research with a strong application orientation, e.g. the United Kingdom, are striving hard to achieve greater government influence over the direction of basic research.[27]

The major vehicle used to influence the direction of basic research has been the setting of priorities. Evidence of its effectiveness, however, remains limited. Priority setting has generally involved the identification of research areas of special interest through interaction between the academic members and professional staff of research funding agencies and varying degrees of consultation with the research community. In some countries fixed sums are allocated for competition in priority areas; in others, the priorities become simply another criterion to be considered in the evaluation of proposals.

A recent Organisation for Economic Cooperation and Development report noted the broadening of the concept of priorities to include not only "thematic" priorities (e.g., identifying areas and problems that deserve greater attention such as optics), but also "structural" priorities (e.g., creating new institutes or research teams, or purchasing equipment and facilities).[28] Indeed the report argues that the two are "indissolubly linked," as thematic priorities cannot be implemented without adequate structural support.

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[25] The number of universities has grown from 20 in 1947 to 160 in 1987. Less than 10 percent of national research and development expenditure goes to the university system for research, a proportion far smaller than that in the other countries reviewed here.

[26] This is a conclusion drawn by economist Harvey Averch in his survey of the literature. See Harvey Averch, "Policy Uses of 'Evaluation of Research' Literature: Post-1985 World Research Evaluation," OTA contractor report, July 1990, annotated bibliography. Available through the National Technical Information Service, see app. F.

[27] Lederman, op. cit., footnote 10, cautions that "striving hard" is not the same as succeeding. No country will soon become as centrally controlled as France. And there is a culture of criticism in some cultures that masks policymaking tendencies. The UK, Canada, and Australia, like the United States, have a tradition of criticizing government. Germany, Japan, and Sweden have little open criticism although problems and dissatisfactions of researchers may be as widespread as in other countries.

[28] Gibbons, op. cit., footnote 20.

In the nine countries reviewed here, the major form of structural priority is greater concentration of research resources through an increase in the funds allocated to long-term programs and centers. Thematic priority setting has also been increasingly applied by the majority of the countries, though (with the exception of the United Kingdom) such priorities represent no more than 20 percent of research agency budgets. These thematic priorities have been established at a number of levels, ranging from the national arena to that of the research agency, from a set of disciplines or problem areas to individual disciplines.

Examination of the mechanisms and experiences of the nine countries in developing and implementing new approaches to the direction of basic research yields four distinct models of priority setting and implementation: structural, thematic disconnected, thematic connected, and systematic. In the following section, these models are applied to the U.S. experience.

Structural

In the United Kingdom, Netherlands, Canada, and to a lesser extent, Australia, the emphasis has been on the application of structural priorities. These have generally followed the principles of concentration, either by allocating more of the resources in larger units, and/or by increasing the small proportion of research funds distributed on a competitive basis. However, concentration alone carries the danger of freezing national capabilities around present or past historical strengths. Structural priority setting thus would not appear to be an appropriate mechanism, of its own, to identify and respond to challenges and opportunities of the future.

The British system would appear to have a particular defect in the extent to which the basis for implementation of structural priorities and determination of thematic priorities occurs behind closed doors by an appointed and nonrepresentative elite. Such a nonparticipative approach would appear to have grave dangers of engendering hostility and resentment among researchers instead of building consensus required for effective priority setting and implementation. In contrast, in the Netherlands bibliometric measures have been developed in an attempt to provide a public and objective basis for structural priorities together with an open and transparent system of evaluation.[29]

Thematic Disconnected

This model is evident in the United Kingdom, Canada and Australia, and for some programs in Japan. It describes the system in which priority setting is effectively disconnected from the priority-implementation process. In each of these countries the establishment of priorities occurs in a relatively closed process, but the implementation is through traditional methods of an open call for competitive proposals, to be evaluated by peer panels together with ad hoc referee reports. Such a system has the virtues of combining thematic priority setting with researcher freedom to develop research programs subject to evaluation. There is a real danger, however, that the priorities would serve as little more than signposts for labeling of projects, and the level of implementation of the priorities could remain quite low. The deep resistance of Canadian and United Kingdom scientists to just such a system would appear to confirm the likelihood of this problem.

Thematic Connected

This model describes systems in which the priority-setting and implementation mechanisms are tightly coupled. Within this model there are two different types. The Federal Republic of Germany represents a bottom-up form of the thematic connected model, in which the scientists themselves are primarily responsible for identifying thematic priorities, but once established, it is essentially the same researchers who are invited to prepare proposals according to negotiated criteria.

The other type is the top-down thematic connected model, which operates in France, India, and less so in the Council for Planning and Coordination of Research (FRN) in Sweden. In these cases, the thematic priorities are identified by research agencies, composed variously of researchers, users, government officials, and community representatives. Then the research agency can work with select individuals and groups to develop proposals that meet the requirements as determined by the agency. For example, though modestly funded, the Swedish FRN provides a positive model of building basic research around societal needs, articulating research problems with relevant research disciplines and specialties.

The top-down thematic connected model has considerable advantages in terms of efficiency and effective implementation. However, it is more likely to be acceptable in a nation where a culture of cooperation and planning is well established. In a more competitive culture this system could be seen as being too readily open to nepotism and political favoritism.

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[29] For example, see A.J. Nederhof and A.F.J. van Raan, "An International Interview Round on the Use and Development of Science and Technology Indicators," report to the Netherlands Ministry of Education and Sciences, Directorate-General for Science Policy, June 1988.

Systematic

This model is best represented in Sweden and France, and perhaps India. In Sweden, an extraordinarily intensive systematic process of consultation, information gathering, and preparation and review of position papers and symposia leads to the drafting of a 3-year research bill that sets the national directions in research. It represents a major exercise in consensus generation that might be far less successful in countries where consensus is not a strong national feature.

Similarly in France, a major systematic effort is being directed to establishing a national capability in research intelligence, foresight, and evaluation. A wide range of foresight exercises[30] have been attempted and two public sector think tanks—the Centre de Prospective et d'Evaluation and the Observatoire des Sciences et Techniques—have been established to attempt to produce indicators, conduct evaluations, and create a national capacity in research evaluation. It remains to be seen whether the work of these units will feed into decisionmaking.

Applications for the United States

As the research economy changes in the United States, the experience of other countries in coping with their research economies can be instructive. However, the institutional structures of policymaking and funding are critical determinants of the way in which governments support basic research and provide a powerful setting to which any new methods of selection must be adapted. Hence any system operating in another country would need to be refashioned to fit another's political culture, structure, and decisionmaking practices.

There are a number of features endemic to the U.S. research system to bear in mind when considering the applicability of the experiences of the nine countries surveyed.

1. In each of the nine countries, the government pays for researcher salaries, support, equipment, and materials through general institutional grants, which are supplemented by competitive funds for research projects. In contrast, the primary funding mechanism for academic research in the United States is competitive support for specific research projects.
2. In the vast majority of the cases in the nine countries, individual researchers and research teams have only one possible source of funds to support their research beyond that available from institutional grants. In the United States, there has been a plurality of potential funding agencies for researchers.
3. In the United States, there is a very high level of absolute funding for basic research, comparable to that of Federal Republic of Germany (once defense research is excluded). In addition, all nine countries have shifted almost all of their big science into international cooperative ventures.

What, then, are the lessons for U.S. agencies? The strategies described above represent experimental alternatives for research decisionmaking.

The structural priorities model describes the Department of Defense in the 1980s and presumably the 1990s, especially in reference to the consolidation of the defense laboratories. Both the thematic disconnected and the thematic connected models might be appropriate for consideration by the National Institutes of Health, the National Science Foundation, the Department of Energy, and the National Aeronautics and Space Administration. Indeed, components of these models are already in place at these agencies. The thematic disconnected model is likely to be most appropriate when the identified thematic priority area is relevant to a range of well-established disciplines. Where a thematic priority is opening up a very new area, sitting at the boundaries of a number of disciplines, or demanding a large allocation of resources, the more directive thematic connected model might prove effective.

However, what is more important in the U.S. context is that the research agencies experiment and evaluate research priorities in a systematic and open way. At the same time, these models and research policymaking in other countries could be monitored for some possibly valuable lessons.

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[30] Martin and Irvine, op. cit., footnote 11.

APPENDIX E

Top 100 U.S. Academic Institutions Ranked by Citation Impact, 1981-88

Rank	Institution	Articles	Citations	Mean
1.	Rockefeller University	4,058	84,718	20.88
2.	Harvard University	30,228	491,663	16.26
3.	California Institute of Technology	8,536	131,923	15.45
4.	Massachusetts Institute of Technology	13,486	195,921	14.53
5.	University of California, San Francisco	14,910	215,487	14.45
6.	Yale University	13,516	194,410	14.38
7.	Stanford University	15,834	225,929	14.27
8.	Washington University	9,384	131,454	14.01
9.	Brandeis University	1,839	24,355	13.24
10.	Princeton University	5,199	68,802	13.23
11.	Yeshiva University	4,522	58,201	12.88
12.	University of Washington	15,770	202,848	12.86
13.	University of Chicago	9,710	122,860	12.65
14.	University of California, San Diego	12,675	159,907	12.62
15.	University of California, Santa Cruz	1,541	19,353	12.56
16.	Tufts University	4,850	60,747	12.53
17.	The Johns Hopkins University	14,325	178,437	12.45
18.	University of California, Santa Barbara	4,022	49,473	12.30
19.	University of Oregon	2,356	28,125	11.94
20.	Dartmouth College	2,380	28,402	11.93
21.	University of Colorado	10,587	123,560	11.67
22.	Vanderbilt University	6,044	70,514	11.67
23.	New York University	7,694	88,943	11.56
24.	Columbia University	11,781	136,067	11.55
25.	University of California, Berkeley	16,347	187,872	11.49
26.	Duke University	9,891	109,954	11.12
27.	University of Pennsylvania	14,108	153,468	10.88
28.	Baylor University	6,933	75,588	10.81
29.	University of California, Los Angeles	20,271	217,515	10.73
30.	SUNY at Stony Brook	6,698	70,367	10.51
31.	Cornell University	16,910	174,873	10.34
32.	University of Texas	30,272	309,240	10.22
33.	Boston University	5,766	58,567	10.16
34.	University of Alabama	6,436	65,206	10.13
35.	University of Virginia	6,414	64,925	10.12
36.	University of California, Irvine	5,641	56,419	10.00
37.	University of North Carolina	9,205	90,821	9.87
38.	University of Minnesota	16,278	158,981	9.77
39.	University of Rochester	7,109	68,519	9.64
40.	SUNY at Albany	1,676	15,744	9.39
41.	Brown University	4,296	40,059	9.32
42.	University of Wisconsin	16,831	155,350	9.23
43.	University of Utah	6,650	61,225	9.21
44.	University of Michigan	14,494	133,444	9.21
45.	Indiana University	7,396	67,852	9.17
46.	University of Southern California	8,393	76,612	9.13
47.	University of Massachusetts	6,307	57,508	9.12
48.	University of Connecticut	4,916	44,749	9.10
49.	University of California, Riverside	3,200	29,030	9.07
50.	University of Pittsburgh	8,264	74,572	9.02

Rank	Institution	Articles	Citations	Mean
51.	University of Houston	2,704	24,393	9.01
52.	Emory University	4,317	38,916	8.99
53.	Rice University	1,683	15,134	8.99
54.	Case Western Reserve	6,471	57,943	8.95
55.	Michigan State University	6,669	59,700	8.95
56.	Northwestern University	8,064	71,841	8.91
57.	University of Arizona	8,550	75,367	8.81
58.	University of South Alabama	964	8,453	8.77
59.	Georgetown University	3,000	26,134	8.71
60.	St. Louis University	2,004	17,396	8.68
61.	University of Miami	4,644	40,197	8.66
62.	University of Iowa	8,469	73,340	8.66
63.	Virginia Commonwealth University	4,003	34,616	8.65
64.	Tulane University	2,850	23,996	8.56
65.	University of Hawaii	3,355	28,730	8.56
66.	University of Maryland	10,730	91,124	8.49
67.	Florida State University	2,175	18,422	8.47
68.	Temple University	3,110	26,258	8.44
69.	George Washington University	2,676	22,544	8.42
70.	Creighton University	571	4,782	8.37
71.	City University of New York	7,279	60,503	8.31
72.	University of Vermont	2,064	17,103	8.29
73.	University of Illinois	18,096	149,643	8.27
74.	Pennsylvania State University	8,257	67,238	8.14
75.	College of William and Mary	558	4,529	8.12
76.	Syracuse University	1,606	12,941	8.06
77.	Carnegie-Mellon University	2,497	20,107	8.05
78.	Brigham Young University	1,052	8,441	8.02
79.	Wayne State University	4,084	32,485	7.95
80.	SUNY at Buffalo	5,119	40,417	7.90
81.	University of Cincinnati	5,282	41,688	7.89
82.	Purdue University	7,878	61,892	7.83
83.	University of New Hampshire	954	7,459	7.82
84.	University of Kansas	4,135	31,903	7.72
85.	University of Rhode Island	1,718	13,178	7.67
86.	University of California, Davis	11,024	83,587	7.58
87.	University of Notre Dame	1,860	13,950	7.50
88.	University of New Mexi[illegible]	3,079	23,008	7.47
89.	University of Tennessee	5,747	42,505	7.40
90.	University of Oklahoma	3,145	23,242	7.39
91.	University of Delaware	2,592	18,517	7.14
92.	Howard University	941	6,617	7.03
93.	Colorado State University	4,003	28,013	7.00
94.	Rutgers State University	4,876	34,094	6.99
95.	University of Alaska	903	6,205	6.87
96.	Ohio State University	8,630	59,178	6.86
97.	Georgia Institute of Technology	1,919	13,086	6.82
98.	University of Georgia	5,137	33,864	6.59
99.	Oregon State University	4,087	26,790	6.55
100.	Iowa State University	4,900	31,539	6.44

NOTE: Citation impact is for the period 1981 to 1988. The mean for all U.S. papers in this period is 9.5. Unless noted otherwise, totals for State universities include all campuses in the university system.

SOURCE: Henry Small, "Bibliometrics of Basic Research," OTA contractor report, July 1990. Available through the National Technical Information Service. See app. F.

APPENDIX F

Contractor Reports

Copies of contractor reports done for this project are available through the National Technical Information Service (NTIS), either by mail (U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161) or by calling NTIS directly at (703) 487-4650.

Harvey Averch, Florida International University, "Analyzing the Costs of Federal Research," PB 91-166 629

Susan Cozzens, Rensselaer Polytechnic Institute, "Science Indicators: Description of Prescription," PB 91-166 611

Patrick Hamlett, Cornell University, "Task Force on Science Policy: A Window on the Federal Funding and Management of Research," PB 91-166 603

James Savage, University of Virginia, "Academic Earmarks and the Distribution of Federal Research Funds: A Policy Interpretation," PB 91-166 595

Henry Small, Institute for Scientific Information, "Bibliometrics of Basic Research," PB 91-166 579

John Sommer, Political Economy Research Institute, "The Research Community Looks at Federal Funding Issues: Results of Sigma Xi Surveys," PB 91-166 587

Rhetorical Analysis of Science Policy Literature, 1960-1990, PB 91-166 637

1. David Birdsell, Baruch College, CUNY, and Herbert Simons, Temple University, "Basic Research Goals: A Comparison of Political Ideologies"
2. Mark Pollock, Temple University, "Basic Research Goals: Perceptions of Key Political Figures"

Project Selection and Research Evaluation Around the World Since 1985, PB 91-166 645

1. Ron Johnston, Techmonitor Ltd., Wollongong, Australia, "Project Selection Methods: International Comparisons"
2. Harvey Averch, Florida International University, "Policy Uses of 'Evaluation of Research' Literature"

APPENDIX G

Workshop Participants and Reviewers and Contributors

Costs of Research and Federal Decisionmaking Workshop, July 12, 1990

Rodney Nichols, *Workshop Chair*
Executive Vice President
Rockefeller University

Harvey Averch
Acting Director
Department of Public Administration
Florida International University
North Miami, FL

Essex Finney
Director of Beltsville Area
Agricultural Research Center
U.S. Department of Agriculture
Beltsville, MD

Howard Gobstein
Government Relations Officer
Research and Technology Transfer
University of Michigan
Ann Arbor, MI

Bernadine Healy
Chairman
Cleveland Clinic Foundation
Cleveland, OH

S. Allen Heininger
Vice President for Research
Monsanto Co.
Clayton, MO

Ruth L. Kirschstein
Director
National Institute of General Medical Sciences
National Institutes of Health
Bethesda, MD

Ron Konkel
Special Assistant to the Associate
Administrator of Space, Science and Applications
National Aeronautics and Space Administration
Washington, DC

William Massy
Vice President for Finance
Stanford University
Stanford, CA

Harold Orlans
Consultant
Chevy Chase, MD

Murray Schulman
Executive Assistant Director
Office of Energy Research
U.S. Department of Energy
Washington, DC

Robert Sproull
Professor
Department of Physics
University of Rochester
Rochester, NY

Amy Walton
Manager
Science Data Analysis and Computing Systems
Jet Propulsion Laboratory
Pasadena, CA

F. Karl Willenbrock
Assistant Director
Scientific, Technological and International Affairs
National Science Foundation
Washington, DC

Reviewers and Contributors

Robert Abel
National Science Foundation

Joseph Alexander
National Aeronautics and Space Administration

John Alic
Office of Technology Assessment

Harvey Averch
Florida International University

Miriam Baltuck
National Aeronautics and Space Administration

Richard Barke
Georgia Institute of Technology

Frederick Bentley
Stanford University

Peter Blair
Office of Technology Assessment

Jennifer Bond
National Science Foundation

Ray Bowen
National Science Foundation

Norman Braveman
National Institutes of Health

Harvey Brooks
Harvard University

Lawrence Burton
National Science Foundation

John Campbell
National Academy of Sciences

Judith Coakley
National Science Foundation

Vary Coates
Office of Technology Assessment

Robert Correll
National Science Foundation

Michael Crow
Iowa State University

John Crowley
Association of American Universities

Joseph Danek
National Science Foundation

Michael Davey
Congressional Research Service

Karl Erb
Office of Science and Technology Policy

Charles Falk
Consultant

Alan Fechter
National Research Council

Michael Feuer
Office of Technology Assessment

Gerald Garvey
Los Alamos National Laboratory

Robin Gaster
Office of Technology Assessment

Michael Gluck
Office of Technology Assessment

Howard Gobstein
University of Michigan

Barry Gold
National Academy of Sciences

Thomas Goodnight
Northwestern University

Edward Hackett
Rensselaer Polytechnic Institute

Richard Hahn
U.S. Department of Energy

C.I. Harris
U.S. Department of Agriculture

Henry Hertzfeld
Consultant

Charles Hess
U.S. Department of Agriculture

Wilmot Hess
U.S. Department of Energy

Christopher Hill
National Academy of Sciences

John Holmfeld
Committee on Science, Space, and Technology
U.S. House of Representatives

James Jasinski
University of Illinois, Urbana

Rhea Jezer
Congressional Caucus for Women's Issues

William Keller
Office of Technology Assessment

Genevieve Knezo
Congressional Research Service

Carlos Kruytbosch
National Science Foundation

Marcel LaFollette
George Washington University

Frank Laird
University of Denver

Neal Lane
Rice University

Joshua Lederberg
Rockefeller University

Leonard Lederman
National Science Foundation

Alan Leinbach
Dames & Moore, Inc.

Tom Lessl
University of Wisconsin, Madison

Arnold Levine
Consultant

Loet Leydesdorff
University of Amsterdam

Hugh Loweth
Consultant

Shirley Malcom
American Association for the
Advancement of Science

Edwin Mansfield
University of Pennsylvania

James McCullough
National Science Foundation

Steve Nelson
American Association for the
Advancement of Science

Rodney Nichols
Carnegie Corp. of New York

Linda Parker
National Science Foundation

Don Phillips
National Academy of Sciences

Michael Phillips
Office of Technology Assessment

Rolf Piekarz
National Science Foundation

Larry Prelli
University of New Hampshire

Linda Roberts
Office of Technology Assessment

Thomas F. Rogers
Consultant

Robert Rosen
National Aeronautics and Space Administration

David Sanchez
National Science Foundation

Frederick Sapp
Consultant

James Savage
University of Virginia

Dick Schoen
National Science Foundation

Jerry Sesco
U.S. Department of Agriculture

Alan Shaw
Office of Technology Assessment

Sonja Sperlich
National Science Foundation

Guyford Stever
Carnegie Commission on Science,
Technology, and Government

Jeffrey Stine
Smithsonian Institution

Linda Stuntz
U.S. Department of Energy

Jane Stutsman
National Science Foundation

Janet Sweet
Stanford University

Albert Teich
American Association for the
Advancement of Science

Michael Telson
Committee on the Budget
U.S. House of Representatives

Alan Title
Lockheed Missiles & Space Co.

John Townsend
National Aeronautics and Space Administration

A.D. Van Nostrand
Georgia Institute of Technology

Betty Vetter
Commission on Professionals in
Science and Technology

Alvin Weinberg
Oak Ridge National Laboratory

John White
National Science Foundation

Ray Williamson
Office of Technology Assessment

Joan Winston
Office of Technology Assessment

Joel Yudken
Rutgers University

APPENDIX H

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